Development of Car/Trailer Handling and Braking Standards. Vol. III: Appendices for Phase I
NTIS, November 1979

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DOT HS-805 328

DEVELOPMENT OF CAR/TRAILER HANDLING AND BRAKING STANDARDS

Volume III: Appendices for Phase I

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Contract No. DOT HS-7-01720
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November 1979
FINAL REPORT

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National Highway Traffic Safety Administration
Washington, D.C. 20590

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16. Abstract

This document contains supportive information relevant to the main technical discussion and results presented in Volume II. This includes all relevant specifications and descriptions of the tow vehicles, trailers, instrumentation, equipment, and test procedures used in the test portion of the program. Also included are supporting data reduced from straight line braking tests, cornering tests, and trailer damping tests. Raw data are contained on 4 FM analog tape. A run log summary is presented to identify conditions of each test run recorded on tape.

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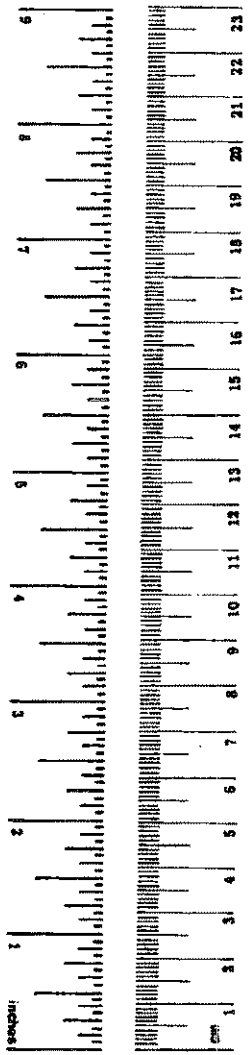
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

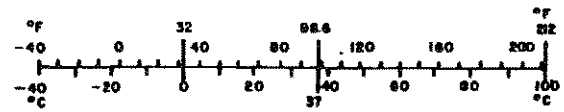
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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



FOREWORD

This document comprises Volume III of a four-volume technical report aimed at developing car/trailer handling and standards. A condensed executive summary of the program and key results is given in Volume I. Volume II contains the main technical discussion and summary test results. This volume contains appendices providing raw data and other supportive material for Phase I.

This program was accomplished by Systems Technology, Inc., Hawthorne, California for the Office of Passenger Vehicle Research of the National Highway Traffic Safety Administration, under Contract DOT-HS-7-01720. The contract technical manager was Dr. J. Kanianthra, and the STI project engineer was Mr. R. Klein. The STI technical director was Mr. I.L. Ashkenas.

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APPENDIX A

TOW VEHICLE AND TRAILER SPECIFICATIONS

This appendix contains all the relevant specifications, measured parameter values, and vehicle equipment descriptions for the three tow vehicles and eight trailers used in the initial test program. These data are presented in Tables A-1 and A-2, respectively.

In addition, there are extended descriptions of special design features of several trailers where they relate to field test results. This includes manufacturers recommendations posted on the trailers, tandem axle roll steer effects, and the unusual pitch down behavior of the horse trailer during brake stops.

LOADING RECOMMENDATIONS IN U-HAUL TRAILER

Recommended loading for the U-Haul trailer was:

- Cargo capacity = 1,680 lb
- Place 61 percent of cargo weight in front half
- Hitch load = 10 percent trailer weight
- Increase air pressure in rear tires of tow car 5 psi above normal
- Tie down partial loads to prevent cargo shift.

TANDEM AXLE ROLL STEER EFFECTS

The way in which typical trailer tandex axles are designed results in a very large amount of differential roll steer in the front and rear axles. This produces an effect on trailer swing motions and steady state cornering equivalent to that of a heavier hitch load. Consequently, for these types of tandem axle trailers, there is the potential for an improvement in trailer swing damping (over that predicted) but a loss in the tow car understeer gradient during cornering. The following analysis quantifies these effects.

TABLE A-1

TOW CAR SPECIFICATIONS

Specifications	Tow Cars		
	Intermediate	Compact	Subcompact
Vehicle	1976 Chevrolet Monte Carlo 2 door coupe	1976 Plymouth Volare 4 door sedan	1978 Ford Mustang 2 door coupe
GVWR	5513 lb	4775 lb	3861 lb
Front	2727 lb	2350 lb	1942 lb
Rear	2786 lb	2475 lb	1935 lb
Veh. Cargo Capacity	1100 lb	1100 lb	700 lb
Passengers	6 passengers	6 passengers	4 passengers
Trunk	200 lb	200 lb	100 lb
Curb Weight			
Front	2320 lb	1960 lb	1515 lb
Rear	1820 lb	1440 lb	1200 lb
Total	4140 lb	3400 lb	2715 lb
Test Weight (including driver but without hitch head)			
Front	2540 lb	2190 lb	1820 lb
Rear	2120 lb	1840 lb	1510 lb
Total	4660 lb	4030 lb	3330 lb
Tire Make	Firestone Radial	Goodyear Polyglass	Michelin Radial
Size	GR-70-15	D-78-14	BR78-13X
Nom. Pressure	28 psi	32 psi (max. load)	32 psi (max. load)
Load range	B	B	B
Load capacity	1620 lb @ 32 psi	1320 lb @ 32 psi	1150 lb @ 32 psi
Construction of Casing	2 steel ply belts 2 ply polyester radial	2 glass ply belts 2 ply polyester bias-belted	2 steel ply belts 2 ply rayon
Rim Width	7.00"	5.00"	4.75"
Steering Type	Saginaw Power Boosted Recirc. Ball	Chrysler, Power Boosted Recirc. Ball	Ford Power Boosted Rack and Pinion
Overall ratio	17.1	20.0	18.75
Hysteresis with no load (at steering wheel)	$\pm 7^\circ$	$\pm 11^\circ$	$\pm 4^\circ$
Wheelbase, ℓ_1	116.00"	112.50"	96.00"
Overhang to ball hitch, ℓ_h	62.75"	58.25"	48.50"
Wheel Track, Front	61.625"	59.50"	56.00"
Rear	61.50"	58.62"	56.00"

TABLE A-1 (Concluded)

Specifications	Tow Cars		
	Intermediate	Compact	Subcompact
Front Suspension	Short and Long Arm Independent	Short and Long Arm Independent	Short and Long Arm Independent
Max. Jounce Travel Available at Test Condition	4.7"	5.17"	(not obvious)
Springs	Coil	Coil	
Anti Roll Bar	Yes	Yes	Yes
Rear Suspension	Solid Axle 4 Bar Linkage Control	Solid Axle Positioned by Leaf Springs	Solid Axle Positioned by Leaf Springs
Springs	Coil	Leaf	
Anti Roll Bar	Yes	No	Yes
Max. Jounce Travel Available at Test Condition	5.0"	5.25"	4.75"
Rear Shock Absorbers Added for Hitch Load Capacity	Gabriel Hy-Jackers "Air Lift" Type	Gabriel Hy-Jackers	Gabriel Hy-Jackers
Brakes			
Front	Vacuum Boosted Disc	Manual Operated Disc	Vacuum Boosted Disc
Rear	Drum	Drum	Drum
Engine and Transmission	350 C.I.D. Automatic Transmission	225 C.I.D. Automatic Transmission	140 C.I.D. Automatic Transmission

TABLE A-2. TEST TRAILER SPECIFICATIONS

Type	Mfg. Model	Weight Specifications					Brakes Mfg./Size/Actuation
		Empty	Test	GVWR	GAWR	Hitch Load	
Utility	U-Haul 5 × 8 3533AV3894	920	1500	2600		10 percent	None
Camper	Starcraft Starmaster 6 1977	1430	1600	2090	2090	180 to 300 curb max.	Bendix, Drum, Surge (not used)
18' Travel	Shasta 1750 1978	2880	3000, 3880	3888	3500	388	Dexter, 10" Drum, Electric
19' Travel	Traveleze	3560	4000	(no tag)			Kelsey Hayes, Drum, Electric
22' Travel	Prowler L 1978	3376	4000	5000	2510 per axle		Dexter, 10" Drum, Electric
27' Travel	Holiday Rambler Statesman 1000 Series 127 1978	5300	6000	6800	3400 per axle		Dexter, 10" Drum, Electric
Boat	American Trailer and Mfg. Co. with 16' Glasbar Boat	3000 with boat	3000	3100	3100		Atwood, 10"Drum, Surge
Horse	Stidham B (2 horse)	2020	2000, 4000, 5800	(no tag)			Interstate, 10" Drum, Electric. On rear axle only

TABLE A-2 (Continued)

Type	Dimensions							
	Wheelbase, ℓ_2, Axle ℄ to Ball Hitch	Length Between Tandem Axles	Track Width	Trailer Box Length × Width	Tongue Length	Overall Height	Floor to Ground Height	Overall Length
Utility	92"	NA	75"	94" × 60"	41"	81.5"	15.5"	11'-6"
Camper	125"	NA	56.375"	124.5" × 80"	50"	53.5"	15.5"	15'-3"
18' Travel	137"	NA	84"	184" × 92"	~30"	100"	20.5"	17'-6"
19' Travel	142"	NA	76.5"	174" × 94"	~34"	100"	17.5"	18'-7"
22' Travel	164"	31.5"	81.5"	222" × 92.5"	~32"	99"	18.5"	21'-8"
27' Travel	202.5"	33"	85"	300" × 94"	~36"	105.5"	14.5	28'-2"
Boat	183"	NA	87.5"	Boat Alone 220" × 86.5"	35" in Front of Boat			19'-10"
Horse	92.75"	33.5"	78"	108" × 60"	20.5"	91"	11.0"	10'-10"

TABLE A-2 (Concluded)

Type	Tires						Suspension Type
	Mfr., Model	Size	Rated Load Capacity	Casing Construction	Rec. Tire Press.	Wheel Rim Width	
Utility	Goodyear U-Haul Traction Hi-Miler	670-15LT	"C" 1530 lb @45 psi	Bias 4 ply nylon	45 psi	5.25"	Solid beam axle Leaf springs Compression shackles
Camper	Goodyear Hi-Lander GT	5:30-12	"C" 1045 lb @80 psi	Bias ply	80 psi	—	Solid beam axle Leaf springs
18' Travel	Goodyear S.T.	8.55 × 15 S.T.	"C" 2000 lb	Bias 4 ply nylon	50 psi	6.00"	Solid beam axle Leaf springs Compression shackles
19' Travel	Triumph L.T.	7.00 × 15 L.T.	"C" 1720 lb	Bias 4 ply nylon	45 psi	5.75"	Solid beam axle Leaf springs Compression shackles
22' Travel	Dayton 78 Thorough-Bred	7.75 × 15 S.T.	"B" 1365 lb @35 psi	Bias ply	35 psi	5.00"	Solid beam axles (two) Leaf springs, tension shackles with front to rear interconnecting linkage
27' Travel	Dayton Thorobred Trailer	7.00-15LT	"C" 1520 lb	Bias 4 ply nylon	45 psi	6.00"	Solid beam axles (two) Leaf springs, tension shackles with front to rear interconnecting linkage Hydraulic shock absorbers at each wheel
Boat	Goodyear Custom Power Cushion Polyglass	H78-14	"B" 1770 lb @32 psi	2 ply fiber-glass belt 2 ply poly-ester casing	32 psi	5.50"	Solid beam axle Leaf springs Compression shackles
Horse	Goodyear All Weather IV	7.75 × 15	"B" 1490 lb @32 psi	Bias 4 ply nylon	32 psi	5.25"	Solid beam axles (two) Leaf springs, tension shackles with front to rear interconnecting linkage (see following detailed description)

Effect of Tandem Axle Geometry on Hook-up Factor

As described in Section IV of Vol. II, "hook-up factor" gives a relative indication of the lateral hitch force on the tow car. This force is acting to cause a tow car yaw response in the same angular direction as the trailer yaw acceleration, and is a maximum when the trailer swing is at its maximum swing amplitude.

Tandem axle geometry effects (due to trailer roll) can produce a side force at the hitch which is in the opposite direction, and thus will help help to improve trailer swing damping. For example, at maximum trailer swing, the trailer roll angle will also be at its maximum, and in the same direction. Using Fig. A-1, it can be seen that if the rear axle is steered clockwise and the front axle counter-clockwise (due to the roll angle) the tire side forces resulting from this differential angle will produce an opposite force at the tow car hitch.

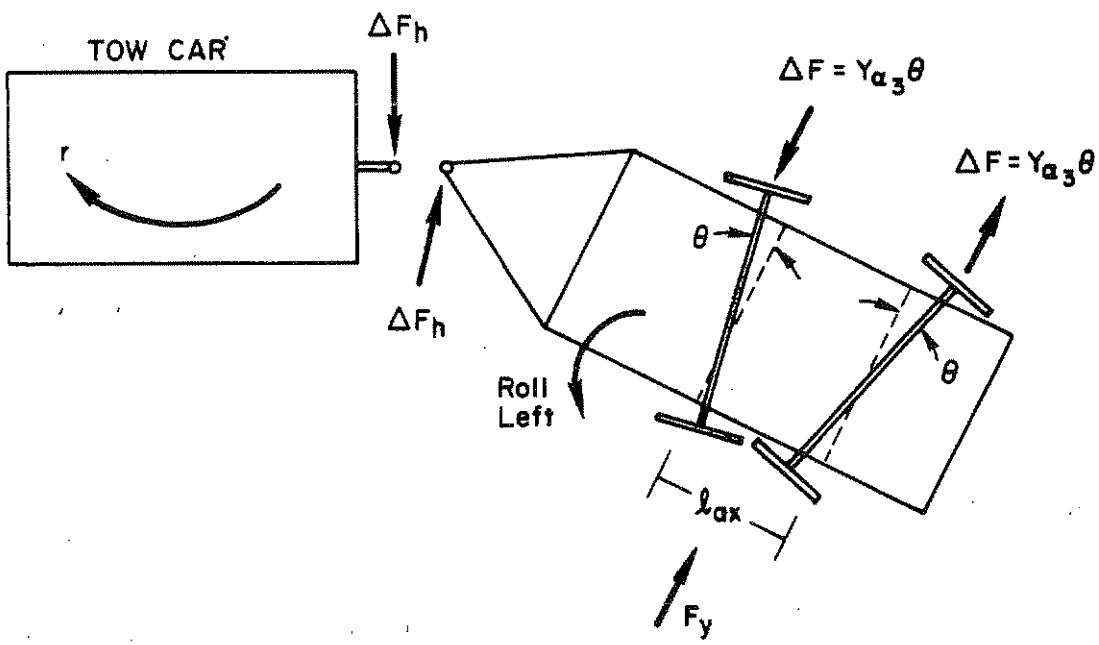


Figure A-1. Tandem Axle Roll Steer Effect on Hitch Force

In Fig. A-1, the incremental hitch force, ΔF_h is given by:

$$\Delta F_h = \frac{Y_{\alpha 3}\, \epsilon\, \varphi\, \ell_{ax}}{\ell_2}$$

where:

$Y_{\alpha 3}$ = Trailer tire cornering coefficient

φ = Trailer roll angle defined by the roll gradient K_R, times the lateral acceleration (in g's), i.e., $\varphi = K_R a_y$

ϵ = Geometric roll steer coefficient. From tandem axle trailer chassis drawings a typical value would be approximately 0.435

ℓ_{ax} = Tandem axle center to center distance

ℓ_2 = Trailer wheelbase (hitch to axle distance)

Since the lateral trailer force, F_y, in steady state cornering is the trailer weight times the lateral acceleration, i.e., $W_t a_y = F_y$, then the ratio of incremental hitch force to total lateral force is given by:

$$\frac{\Delta F_h}{F_y} = \frac{Y_{\alpha 3}\, \ell_{ax}\, \epsilon\, K_R}{\ell_2 W_t}$$

Assuming typical parameters such as ℓ_{ax} = 33 in., ϵ = 0.435, K_R = 5, and $Y_{\alpha 3}$ (for two tires) = 300 lbs/deg

$$\frac{\Delta F_h}{F_y} = \frac{21500}{W_t \ell_2}$$

For the 22 ft travel trailer, ℓ_2 = 164 in, W_t = 4,000, then

$$\frac{\Delta F_h}{F_y} = \frac{21,500}{4000 \times 164} = 0.0328$$

Since this factor is acting in the opposite direction to the regular hookup factor given by Eq. 11 in Vol. II, it must be substracted from it.

In terms of effective hitch load, the tandem axle design has the potential of increasing the hitch load by about 5 percent. This can be determined from Table 17 in Vol. II by comparing the hookup factors at 5 percent and 10 percent hitch load, i.e., HUF changes from 0.094 to 0.063.

EFFECT OF TANDEM AXLE ROLL STEER ON TOW CAR STABILITY FACTOR

In steady state cornering, the incremental hitch force ΔF_h, is acting like an added hitch load on the tow car, i.e., acting on the tow car hitch in a direction of decreasing understeer. For example, the ordinary lateral hitch force due to hitch load is simply the hitch load times the lateral acceleration. Thus the roll steer effect has a direct equivalency as a hitch load, i.e.,

$$\Delta HL = \frac{\Delta F_h}{a_y} = Y_{\alpha_3} \frac{\ell_{ax}}{\ell_2} \epsilon K_R$$

For the 22' travel trailer, the effect of the tandem axle roll steer is a hitch load equivalent of:

$$300\left(\frac{33}{164}\right)(0.435)(5) = 131 \text{ lb}$$

Therefore the effect of the tandem axle roll steer is equivalent to adding 131 lb (or 3.3 percent) more hitch load.

It should be noted from the above calculations that the effect of this tandem axle steer design feature is not a cure-all, but merely a tradeoff. The effective hitch load is increased which produces improved trailer swing damping at the expense of having less tow car understeer. From a practical standpoint the benefit of this feature is that trailers with tandem axles may utilize 3 to 4 percent less hitch load than an equivalent single axle trailer.

HORSE TRAILER TANDEM AXLE DESIGN

The tandem axle suspension design of the Stidham trailer uses tension shackles. The way in which these tension shackles are interconnected, via a pivoting lever arm, causes the suspension to be unstable in the pitch direction. In other words, the lower the tongue the higher the down force exerted by it. Not only does this effect interfere with obtaining consistent hitch load settings but it makes brake tests meaningless.

The following brief description is provided to show why this trailer suspension reacts the way it does. Figure A-2 shows the horse trailer suspension orientation at a trailer weight of 4,000 lb. The shackle orientation and static loads at 10 percent HL are given in Fig. A-3.

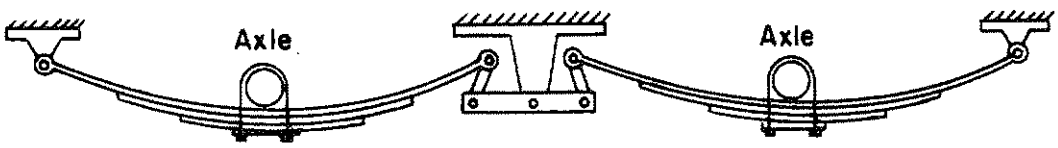
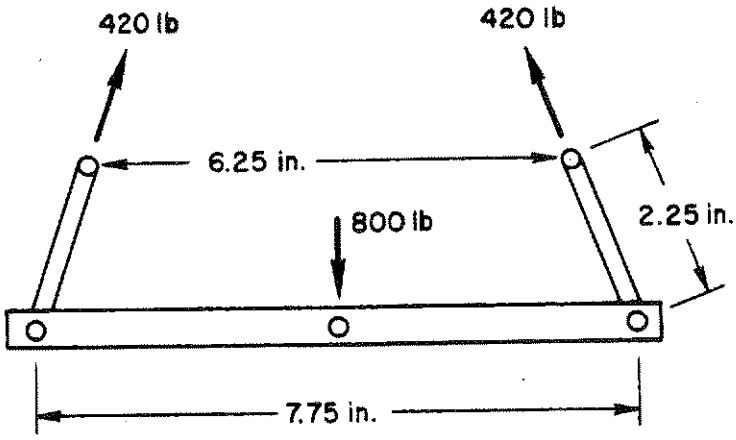


Figure A-2. Side View of Horse Trailer Suspension



Note: At a trailer weight of 5,800 lb, the angles were more extreme, i.e., the 6.25 in. dimension closing to ~5.65 in. and the shackle forces increasing from 420 lb to 690 lb

Figure A-3. Shackle Orientation and Loads at 10 Percent Hitch Load

The main problem with this suspension is the nonlinear variation in hitch load. Without the ability to use load leveling bars, the hitch height cannot be maintained statically. Upon hookup to the tow car, the hitch load causes a drop of as much as 4 in. from the original height. This in turn increases the hitch load further, or about 5 percent from that intended. This effect was amplified in test procedures where application of only moderate brake deceleration rates would cause the trailer to pitch down into the road surface.

This unstable pitch rate does not continue indefinitely however. As the center rocker arm angle becomes larger, it tends to limit at some maximum angle. At this point the individual axle deflection rates resume their nominal rate derived from the springs alone, without rocker arm deflection. At this point the hitch load decreases rapidly with pitch down at the hitch. This effect is shown in Fig. A-4.

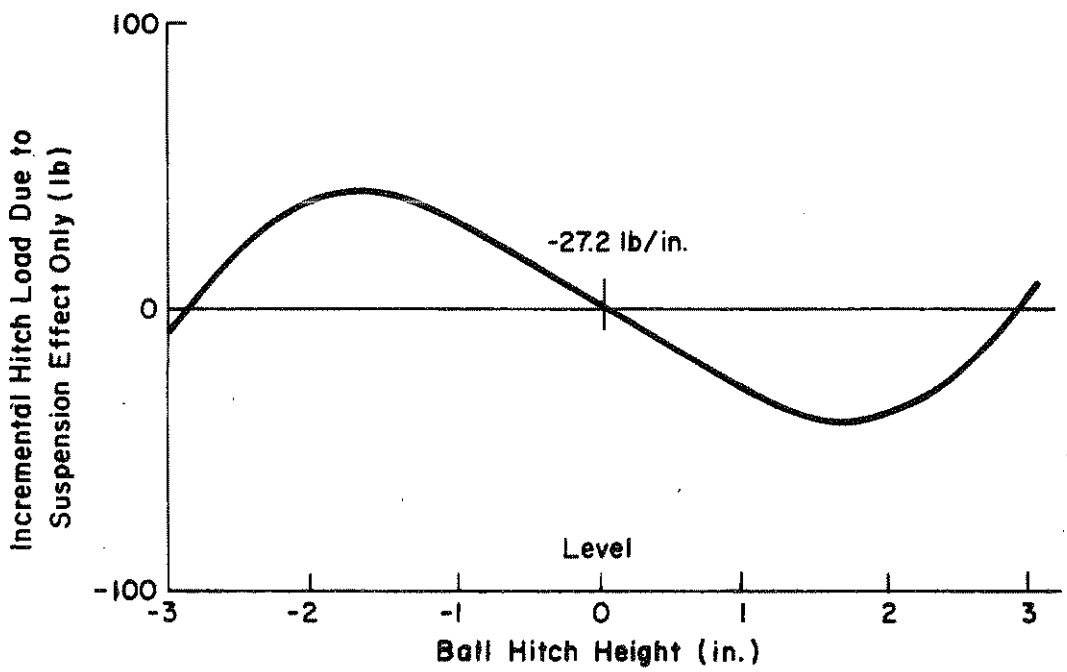


Figure A-4. Incremental Hitch Load Due to Suspension Effect Only

From this figure it can be shown that the hitch load will increase approximately 27 lb for each inch the hitch point is lowered. Hitch load will

also increase due to the forward motion of the center of gravity when the hitch point is lowered (about 15 lb/in for the 4,000 lb test trailer), consequently the total increase in hitch load will be about 42 lb/in. This effect can be viewed as an unstable pitch rate since any trailer rotation will tend to increase the motion further.

With the 5,800 lb test weight configuration, the unstable pitch rate is more dramatic (see Fig. A-5) and can change the hitch load as much as 80 lb.

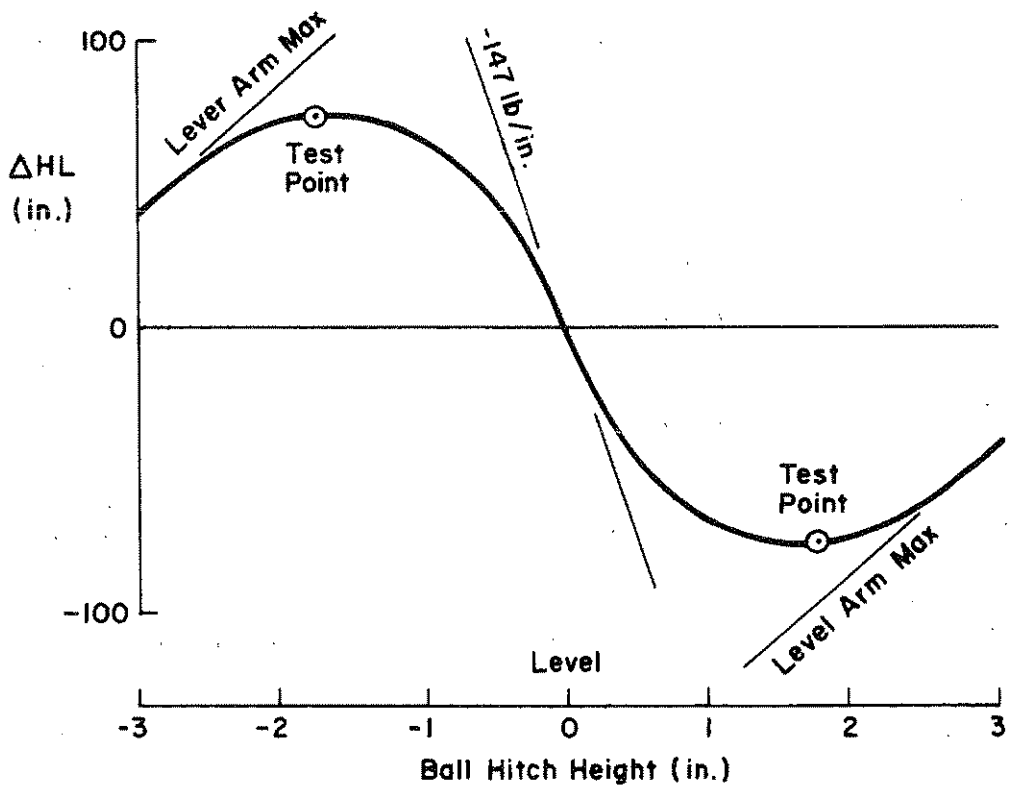


Figure A-5. Incremental Hitch Load Due to Suspension Effect Only, Heavy Weight Configuration

In summary, this suspension design exhibits an unstable hitch load variation due to the shackle angle. Most other tandem axle trailers (with leaf spring suspensions joined at the middle with an interconnecting rocker arm) have tension shackles splayed at angles away from each other. This places only tension forces horizontally in the rocker arm, which then results in a stable state for all suspension motions.

It is possible that this type of suspension may tend to smooth out the ride qualities for the horse's benefit, with its bogie-wheeled type action. But certainly the use of load leveling bar devices, or conversion to different shackle angles, would make this trailer more acceptable for towing by ordinary passenger cars.

APPENDIX B

FULL-SCALE INSTRUMENTATION, TEST EQUIPMENT, AND TEST PROCEDURES

The purpose of this appendix is to document the instrumentation, test equipment, and test procedures used for the full scale tests. This includes the onboard vehicle instrumentation (i.e., sensors, signal conditioning electronics, and recording devices) and the peripheral test equipment such as the brake actuators, check chains, jackknife limiter, etc., that were necessary to conduct some of the test procedures. Nine dynamic test maneuver procedures and two static test measurement methods are described.

INSTRUMENTATION

Sensors For Magnetic Tape Recording

Eight basic sensors were installed on each combination vehicle. These included the following:

Steering Wheel Angle. A potentiometer was mounted on the steering column and gear driven by the steering wheel.

Yaw Velocity. A yaw rate gyro was mounted to the floor pan, in the mid-car location.

Trailer Articulation Angle. A special apparatus designed and built under DOT-HS-4-00900 was used to measure the trailer articulation angle relative to the tow car. This consisted of a parallelogram type structure with two orthogonal gimbals on the car side and two orthogonal gimbals on the trailer side as shown in Figs. B-1 and B-2. The two gimbals attached to the car bumper above the ball measure trailer yaw (about the vertical shaft aligned with the ball). Although not used, the apparatus also measures pitch angle (as a rotation about the horizontal shaft), and trailer roll (about the longitudinal shaft).

Forward Speed. A Nucleus NC-7 fifth wheel was attached to the trailer rear frame/or bumper to record forward speed.

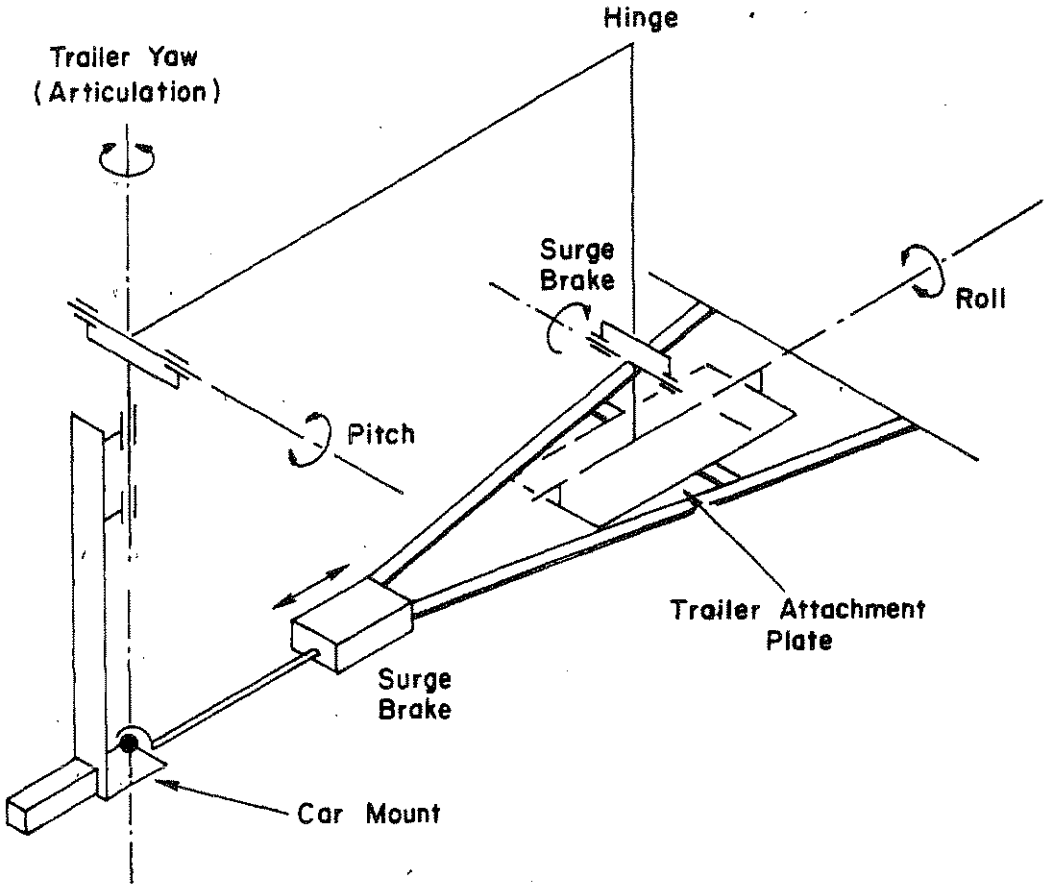


Figure B-1. Schematic Diagram of Car/Trailer Hitch Instrumentation

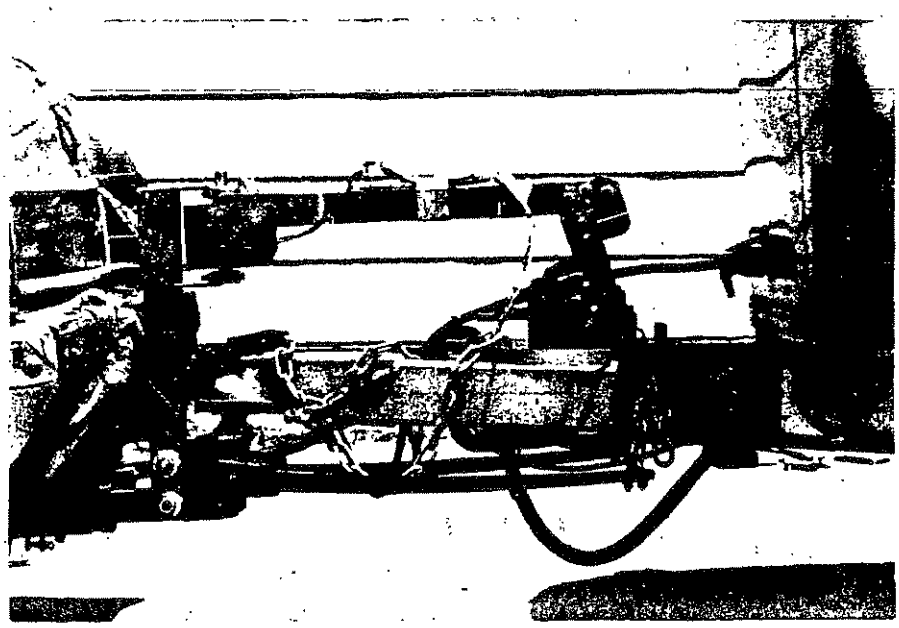


Figure B-2. Photograph of Hitch Instrumentation

Brake Stop Deceleration. An accelerometer was mounted on the floor pan, in the mid-car location, with sensing fore an aft acceleration. This is a sprung mass mounting, and small pitch motions observed on brake stops required about a 5 to 10 percent correction factor (actual less than measured).

Brake Pedal Force. A load cell was mounted to the brake pedal pad to record applied force during brake stops.

Tow Car Brake Line Pressure. A pressure transducer was installed in the brake line at the master cylinder.

Trailer Brake Signal. For electric trailer brakes, the electric voltage applied to the trailer brakes was recorded directly after going through the signal conditioner box.

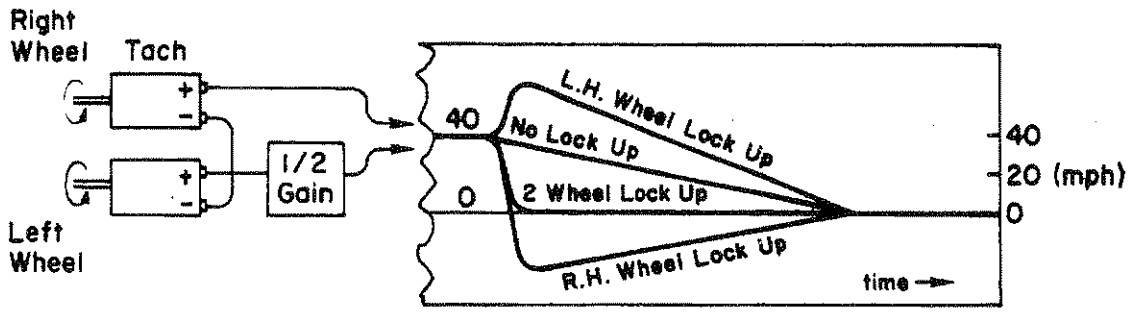
For hydraulic surge brakes, a pressure transducer was installed in trailer brake line.

Non-Tape Recorded Sensors

Several other variables were measured, but not recorded on magnetic tape. These are as follows:

Brake Stopping Distance. A Nucleus NC-7 fifth wheel was attached to the trailer rear frame/or bumper. An electronic revolution pulse counter, with digital read-out, provided distance travelled. The count was initiated by the brake light signal voltage.

Wheel Tachometers. A direct drive tachometer was mounted to each road wheel hub (as many as 8 for a CV). These were used as indicators of wheel lock-ups occuring during a brake stop test. During brake stops, these wheel tach data were switched into the on-board strip chart recorder. In order to conserve on strip chart channels, the left and right hand wheel tach for each axle were electronically summed into one signal as sketched below. In this way, lock-up at either wheel of one axle could be determined by the pattern of the signal tracing on one strip chart channel.



Strip chart time history for brake stop from 40 mph

Brake Lining Temperatures. Thermocouples were installed at each brake lining, and temperatures read out on a meter between test runs.

Signal Conditioning

Sensor outputs were scaled in a signal conditioning unit prior to tape recording. This unit provides either "high" or "low" gain, thus tests having small amplitude motions used high gain and tests having large motions used low gain. Also, there is a built-in "tape calibration" that applies a reference of ±5 volts, or ground, to all recording channels prior to each run. Finally, a reference voltage can be applied to the signal conditioning input side to simulate an incoming sensor voltage. In this mode, changes in scale factors can be accomplished without actually moving sensors. Each channel is also limited to ±10 volts so that the FM recorder will not be overmodulated.

Recording

Data were recorded on a 14 channel Honeywell 5600 C FM tape recorder. Tape speed was 1-7/8 ips with center frequency 3.375 KHz (intermediate band).

Also an 8 channel MFE strip chart recorder was used in the tow car on all test runs. Data channel allocation, scale factors, and selection of variables to record vs. type of test run, are shown in Tables B-1 to B-3. Figure B-3 shows the location of all equipment in tow car.

TABLE B-1. SENSOR SCALE FACTORS

SENSOR VARIABLE	VARIABLE DESCRIPTION	SIGNAL CONDITION CHANNEL	TAPE RECORD CHANNEL	STRIP CHART CHANNEL	HIGH GAIN
δ_{sw}	Steering Wheel Angle	1	1	1	10 deg/V 20 deg/V*
r	Yaw Velocity	13	5	3	2 deg/s/V
η	Car/Trailer Articulation Angle	20	8	2	1 deg/V
U_o [1]	Forward Speed	17	7	4	4 mph/V
a_x	Longitudinal Acceleration	15	6	5	0.10 g/V
F_p [2]	Brake Pedal Force	2	2	6	10 lb/V
P_b [3]	Tow Car Brake Line Pressure	7	4	7	50 psi/V
Elect. B_t	Trailer Brake Voltage	5	3	8	1.0 V Brake 0.85 Volts
Boat Surge B_t'	Trailer Brake Pressure	6	3	8	50 psi/V
$\omega_1 - \omega_2$	LF, RF, Tow Car Wheel rpm (front)	25		1	Strip Chart Pattern
$\omega_3 - \omega_4$	LR, RR, Tow Car Wheel rpm (rear)	26		2	
$\omega_5 - \omega_6$	LF, RF, Trailer Wheel rpm (front)	27		7	
$\omega_7 - \omega_8$	LR, RR, Trailer Wheel rpm (rear)	28		8	

*With Plymouth Volare and Ford Mustang

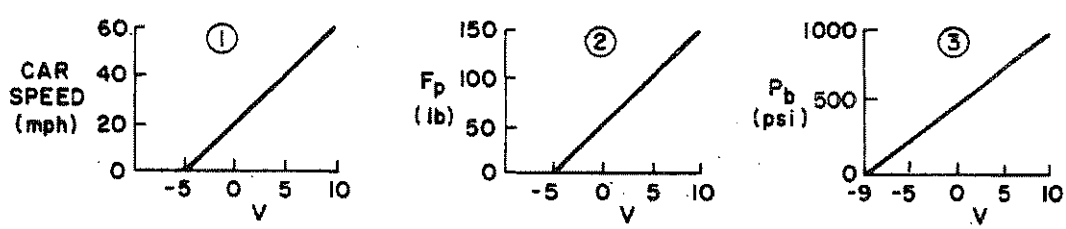


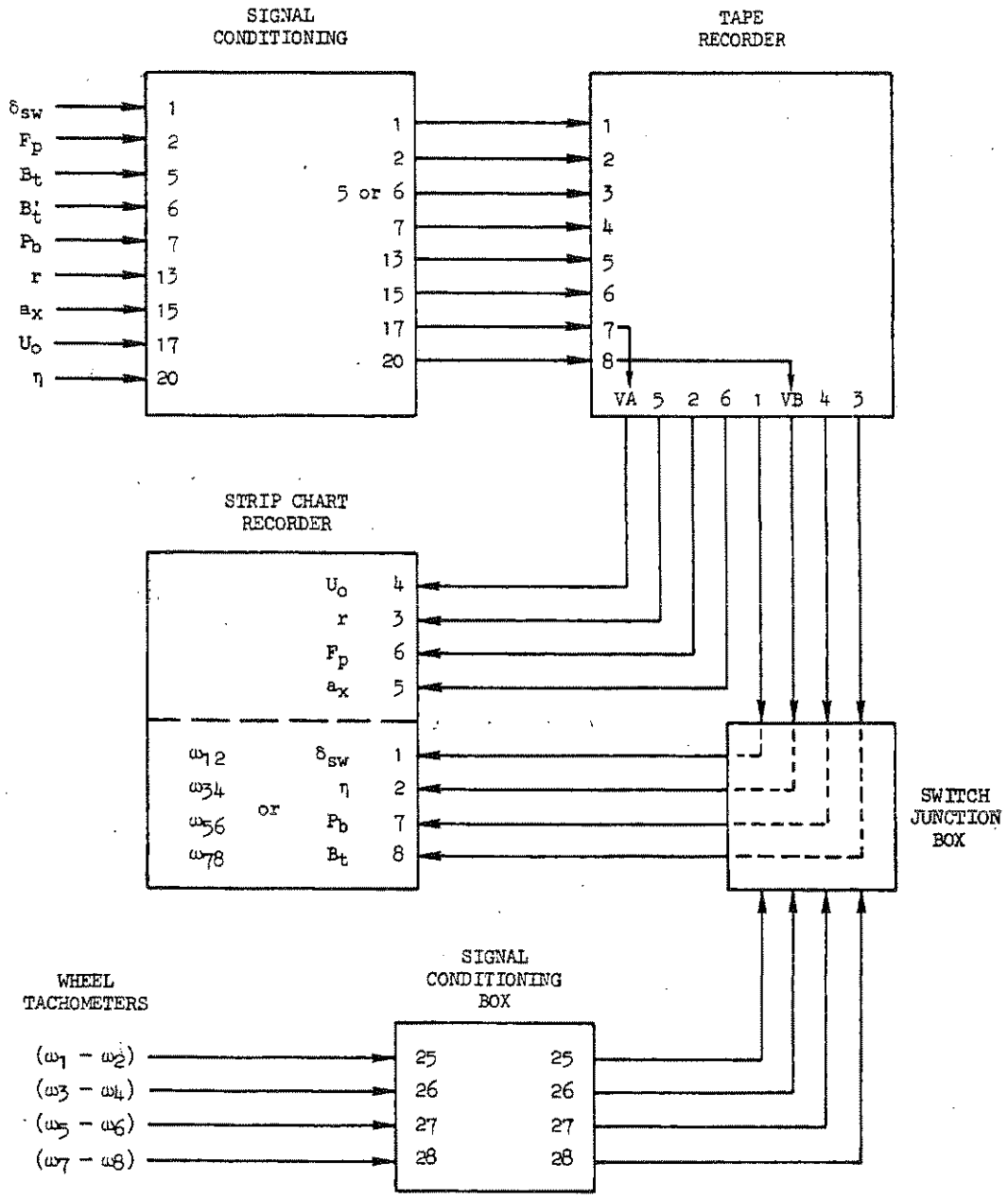
TABLE B-2. DATA RECORDING SCHEME

SENSORS	MANEUVER							
	TAPE RECORDED				STRIP CHART RECORDED IN CAR			
	SS	PS	BIT	SLB	SS	PS	BIT	SLB
8 Wheel Tachometers							×*	×*
δ_{sw}	×	×	×	×	×	×		
r	×	×	×	×	×	×	×	×
η	×	×	×	×	×	×		
U_o	×	×	×	×	×	×	×	×
F_p	×	×	×	×	×	×	×	×
a_x	×	×	×	×	×	×	×	×
P_b	×	×	×	×	×	×		
B_t	×	×	×	×	×	×		

Note: SS = Step Steer
PS = Pulse Steer
BIT = Brake in Turn
SLB = Straight Line Brake

*On 4 Channel

TABLE 3. SENSOR SELECTION, SIGNAL CONDITIONING, AND RECORDING



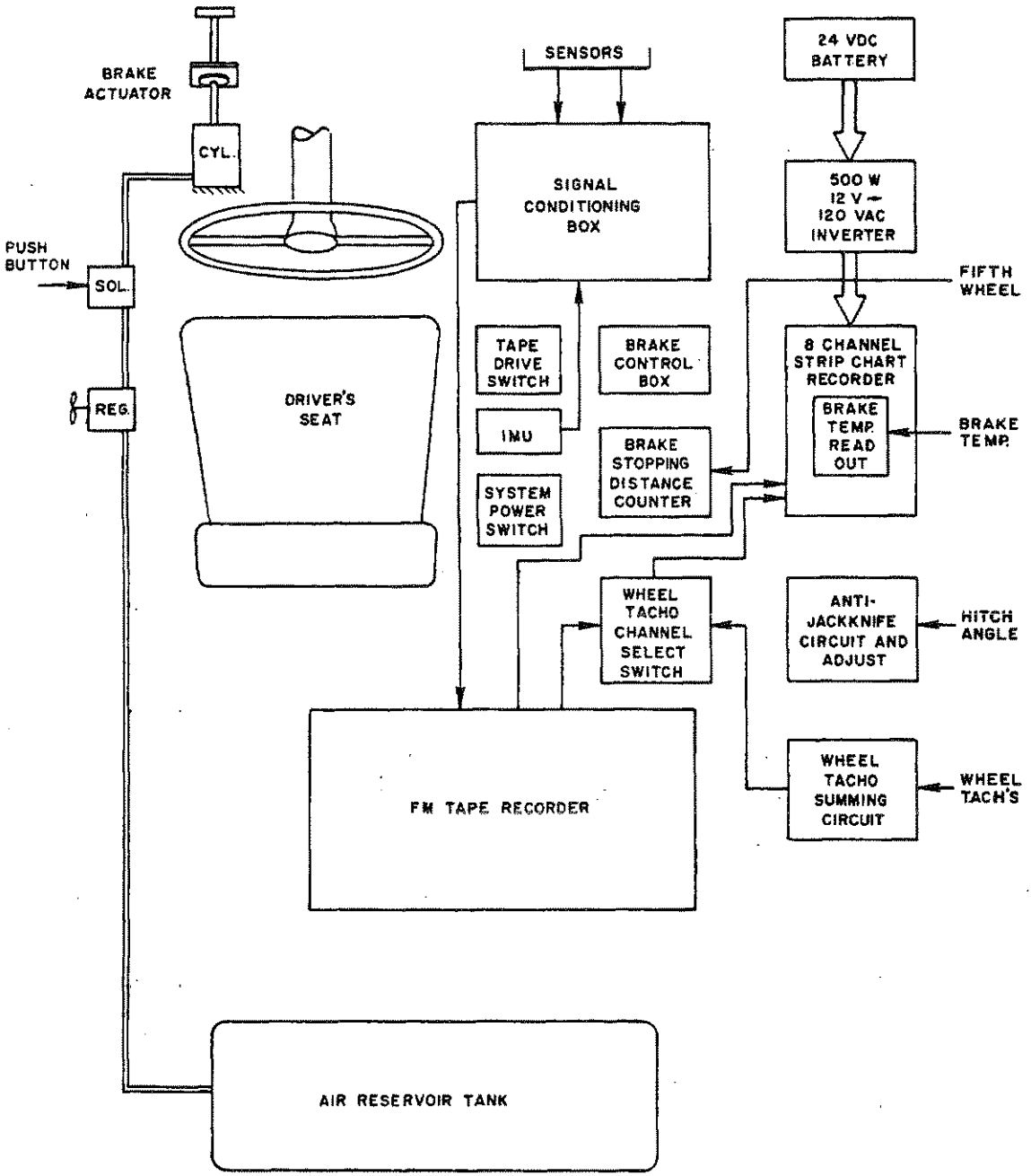


Figure B-3. Equipment Location in Tow Car

PERIPHERAL TEST EQUIPMENT

Brake Actuator

To provide a constant and repeatable brake pedal force, an electro-pneumatic actuator was installed on the brake pedal. A pressurized (120 psi) air tank in the tow car provided the air supply through a pressure control valve. By selecting a given pressure at the valve, the actuator provided a repeatable step force to the brake pedal for up to 4 in. of travel. The test driver electrically triggered the actuator by applying 28V to a solenoid relay. Releasing the switch released the force.

Steering Wheel Input Limiter

To provide repeatable limit stops for step steer tests, a strap was attached from the floor to a receiver on the steering wheel with a removable shear pin. Various step sizes were obtained by varying the strap length.

Jackknife Limiters

Since it was desirable to test each vehicle configuration up to and including jackknife, an anti-jackknife system was developed for the three test vehicles. For the electrically braked trailers this was accomplished by actuating the electric brakes when the hitch angle exceeded 15 deg, as determined by electronic threshold and absolute value circuits. For brake-in-turn tests the system also opened the circuit to the tow car brake actuator, thus leaving only the trailer brake on.

For the surge brake trailer, the anti-jackknife circuit turned on the auxiliary brake actuator system which applied the trailer brakes.

Auxiliary Brake Actuator System For Surge Brake Trailers

To determine trailer-alone brake capacity for surge brake trailers, it was necessary to develop an auxiliary brake actuator. This device, shown schematically in Fig. B-4 was mounted on the trailer tongue and tied into the trailer hydraulic brake line. The trailer surge brakes could be actuated

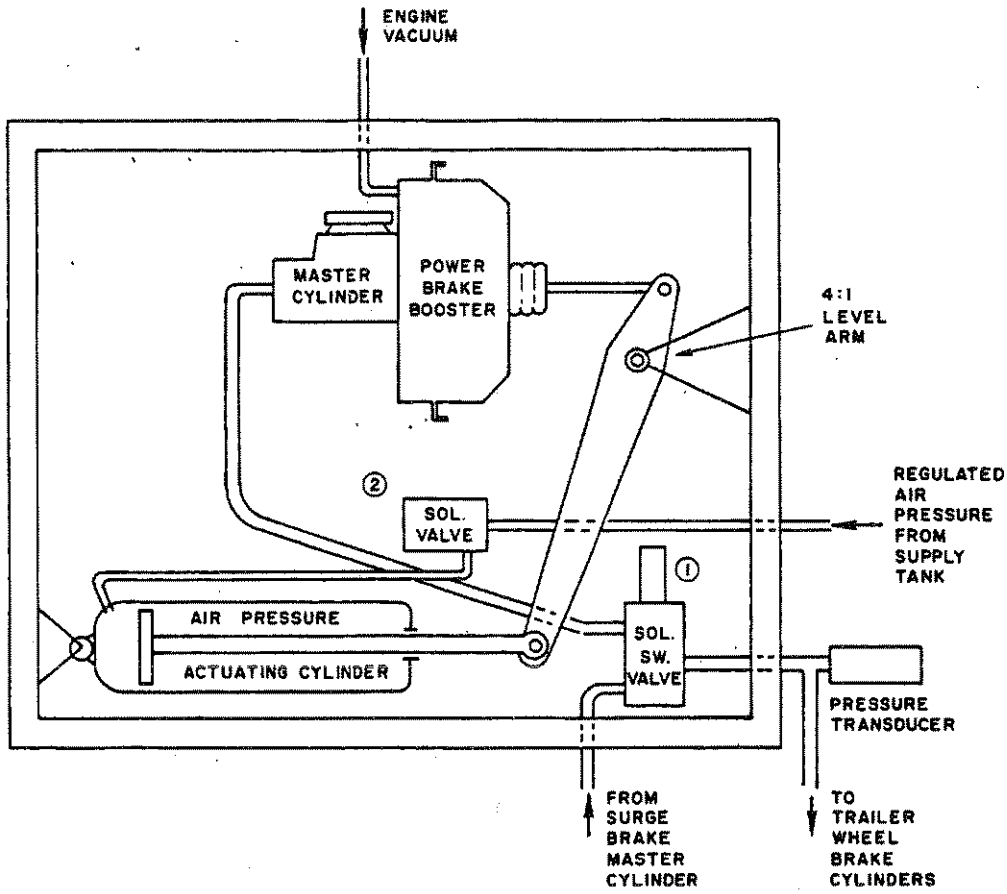


Figure B-4. Brake Actuator System for Surge Brake Trailers

separately, at various preset pressure levels, to determine the brake capability at increasing line pressures. By further determining the line pressure per unit horizontal hitch force, it was possible to compute the surge brake gain, and hence the trailer alone-brake capability.

A description of the system shown in Fig. B-4 is as follows:

1. The solenoid switching valve is a 2-way spool valve which opens the trailer brake hydraulic line to the surge brake master cylinder or to the auxiliary brake actuator master cylinder, whichever is desired for a particular test.

2. The regulated air pressure level is preset to produce a given hydraulic line pressure whenever the driver-controlled pushbutton activates the solenoid valve. With the 2.25 in. diameter pneumatic cylinder, 30 psi air pressure produces about 800 psi hydraulic line pressure, without vacuum boost. With vacuum boost, the gain is much greater, depending on available engine vacuum.

For anti-jackknife protection the trailer brakes were activated whenever the hitch angle exceeded 15 deg. In this mode, this circuit switched the solenoid valve to the auxiliary brake actuator hydraulic line, activated the air pressure solenoid valve, and released the tow car brake actuator.

Individual Wheel Platform Weighing Scales

Eight scales were used to weigh combination-vehicle wheel load distributions, the percent transfer of hitch load to the tow car front axle by the use of load leveling bars, and the trailer hitch load.

TEST MANEUVERS

The following describes nine maneuvers used in the test program. The first four represent those recommended in Ref. B-1. The remaining tests served as backup or to determine supportive measures.

Step Steer Test (SST)

A constant amplitude step steer is input and held for a minimum of 90 deg of path change at a constant speed. The test is rerun at speeds between 10 and 50 mph, in 5 mph increments, to provide data points for the understeer gradient analysis. When a combination vehicle has a jackknife potential (i.e., high hitch load), additional 2.5 mph test speed increments are used in order to obtain data points in the transition range to jackknife. Also, when a tow car exhibits a breakaway from its initial understeer gradient at low lateral acceleration levels, then additional 2.5 mph test speed increments are used in this low cornering level range so that breakaway can be measured.

In order to provide amply opportunity for each CV to reach at least 0.5 g cornering before reaching the 50 mph test point, the steering

amplitude for the step steer was individually set for each CV configuration such as to produce 0.3 g lateral acceleration at 30 mph. With this format, typical jackknife prone CV's tended to oversteer and jackknife in the 35 mph to 45 mph range.

Coast Down Steer Test (CDT)

The purpose of this test is to show up differences in steering response and stability factor due to the high level of engine power application needed in the constant speed step steer runs. As opposed to the normal step steer test, this procedure starts from a given speed and merely allows the CV configuration to "coast-down" in speed with the transmission in neutral.

Constant Radius Turn Test (CRT)

This procedure requires radius turn circle at speeds between 10 and 40 mph. Each speed is held for a minimum of 180 deg. The speeds are chosen to produce equal increments of lateral acceleration up to 0.535 g at 40 mph. If the CV configuration response is nonlinear, the increments should be as small as 0.05 g. Both left and right hand tests are done (as with the SST). Although the driver must exercise closed-loop steering control to follow the 200 ft radius circle (painted on the pavement) simple averaging of the steering wheel angle signal provides very accurate data points for the steer angle, δ_w vs. lateral acceleration, a_y plot. When divided by the overall steering ratio, the slope (at any point) of steering wheel angle vs. a_y plot gives the stability factor in deg/g.

These CRT tests basically provide replication of SST results. However, the CRT test provides more detail data in the transition range to a jackknife response and provides determination of understeer gradient at specified a_y level, up to a maximum of 0.535 g.

Pulse Steer (PS)

The pulse steer test consists of a rapid steering wheel input (and return) to excite the trailer articulation angle (swing mode) dynamics while traveling in a straight line at 55 mph. The trailer articulation angle response is used to evaluate trailer swing mode frequency and damping ratio. These

dynamics influence tow vehicle yaw rate response, degrade driver/vehicle stability in lane regulation tasks, and increase driver workload. Trailer swing mode damping is also important in determining vehicle response to external inputs (e.g., roadway and lateral wind gusts). The principal performance measure is swing mode damping ratio.

This test can also be done with free steering wheel control after the controlled steering wheel pulse input has reached its peak amplitude. Even though this task is not representative of normal driver behavior, it is a test many vehicle test engineers do in development of new cars. In essence, the steering free version of this test shows effects that could be related to excessive free play in the steering system, or to drivers who allow the steering wheel force feedback to move the wheel.

Trailer Alone Swing Damping
Test Procedure

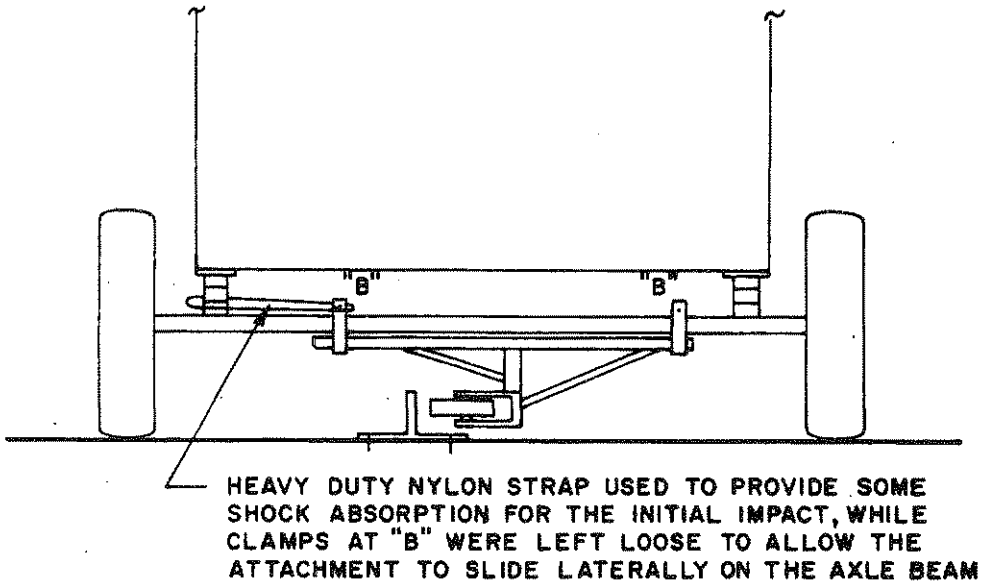
It has been shown in Volume II that the trailer swing damping ratio is lower as a combination vehicle (ζ_{cv}) than if it were connected to an infinite weight tow car. In this latter case, the damping is given by the trailer alone damping equation (ζ_{ta}).

To validate the analytical expression for trailer alone damping, the trailer hitch load was set at a level which reduced the lateral hitch force to zero. This corresponds to having zero "hook-up factor" in Eq. 10 of Vol. II. This condition is satisfied when $I_{t_o} = M_t eh$. Since the percent hitch load is equal to $(h/\ell_2) \times 100$, then the lateral hitch force is zero when the percent hitch load is equal to

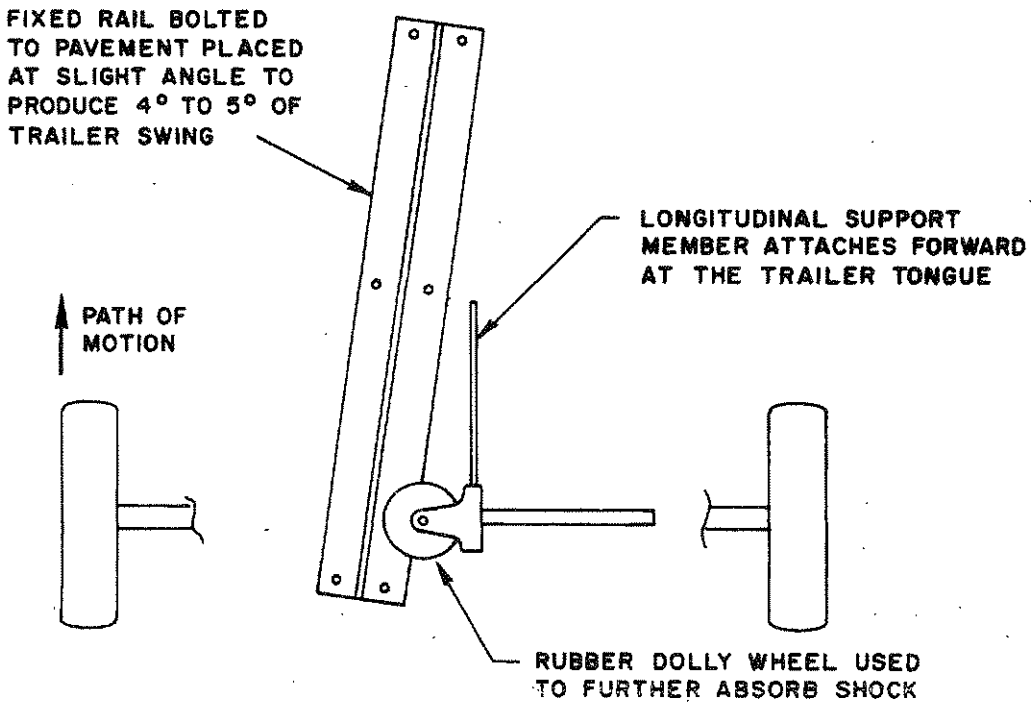
$$\%HL = \frac{100 \quad I_{t_o}}{\ell_2 M_t e} \text{ (for HUF = 0)}$$

Since the trailer alone damping ratio is rather large, there is very little swing after the first excursion. Therefore, a separate means was developed to apply forces at the trailer tire longitudinal position.

This involved bolting a steel rail to the road surface at a slight angle to the test path. A wheel was mounted to the trailer beam axle facing laterally so it would run against the vertical face of the rail. This apparatus is shown in Fig. B-5.



a) Trailer Rear View



b) Plan View of Disturbance Assembly

Figure B-5. Apparatus for Trailer Alone Damping Test Procedure

The test procedure included the following steps:

1. Markers were placed at the steel rail so that the driver could aim the car at the marker. To provide for a margin of error, this aim point placed the trailer dolly wheel in contact with the midpoint of the rail point.

2. The test path angle was adjusted to provide about 4 to 5 deg initial trailer hitch angle, depending on the vehicle speed.

3. Test speeds were increased up to the maximum of 55 mph.

4. Data from all runs were analyzed by determining second order system damping ratio at each given test speed. Data were normalized to the reference speed of 55 mph using the equation

$$\zeta_{ta_{55}} = \zeta_{ta_{\substack{\text{at test}\\ \text{speed}}}} \frac{U_{test}\ (\text{mph})}{55}$$

Example test data for the intermediate sized tow car with 1500 lb utility trailer are given in Table B-4 below. For this trailer, the hitch load was set at 21 percent.

TABLE B-4. TRAILER ALONE DAMPING TEST DATA FOR 1500 LB UTILITY TRAILER

RUN NO.	TEST SPEED (MPH)	DAMPING AT TEST SPEED (ζ_{ta})	CORRECTED DAMPING TO 55 MPH ($\zeta_{ta_{55}}$)	PREDICTED DAMPING 55 MPH
153	29	0.58	0.306	
154	41	Swing amplitude too small	×	
155	45	0.345	0.282	.330
156	45	0.36	0.295	
158	47	0.35	0.299	
160	48	0.345	0.301	
163	47.5	0.345	0.298	

Average of Runs 153-163 = 0.297

Trailer Swing Damping for Non-Zero Lateral Accelerations

This procedure utilized the constant radius circle test and was designed to expose the light hitch load configurations to medium lateral acceleration levels, and to examine the subsequent loss in swing damping ratio. The single data point recorded was the speed at which the damping ratio went to zero. This can be compared to the straight ahead speed for zero damping. The drop in this critical speed can be assigned mainly to the loss in trailer tire cornering stiffness at the steady state lateral acceleration level.

Straight Line Braking

The objective of this test was to determine minimum stopping distance. This test consists of applying a step brake pedal force (via an electro-pneumatic actuator) to the combination-vehicle at 40 mph. The preset brake force applied to the brake pedal is increased until wheel lockup occurs at one wheel. With slight variations in this pedal force adjustment three brake stops are made just under wheel lockup conditions and three stops are made with lockup occuring at one wheel. Stopping distance is recorded for each run, with the fifth wheel distance counter being initiated by the brake light switch.

Trailer Alone Braking

This test is equivalent to the straight line brake described above for the combination vehicle, however, in this application, the object is to obtain data on the brake effectiveness of the trailer at increasing brake force inputs. Brake voltage inputs varying from 0 to 12 volts (in 1 volt increments) were typically used for the electric braked trailers. A similar spread was applied to the surge braked trailer, however in this case, brake-line pressure represented the input. In all cases, the output performance measure was the brake force developed by the trailer brakes, and this data was plotted versus the input variable (i.e., voltage or pressure).

Since the trailer cannot be physically tested "alone," actuation of the trailer brakes alone means that the entire combination-vehicle is being decelerated by only the trailer brakes. In order to keep energy absorption

equivalent to a trailer alone brake stop, the total distance travelled during braking the combination should be the same as if the trailer were stopping only its own weight. This same effort can also be accomplished by decelerating the combination from an initial speed, U_o, to a final speed, U_f. This speed increment is calculated as follows:

For the C-V, the stopping distance, x, and deceleration, a_x, are given by:

$$x = \frac{U_o^2}{2ga_{x_1}}$$

where

$$a_{x_1} = \frac{\mu(W_c + W_t)}{W_c + W_t}$$

For the trailer alone, the distance and deceleration would be:

$$x = \frac{U_o^2 - U_f^2}{2ga_{x_2}}$$

where

$$a_{x_2} = \frac{\mu(W_t - HL)}{W_c + W_t}$$

Since the stopping distances must be equal, the equations may be rewritten, together, as:

$$\frac{U_o^2}{2g\mu} = \frac{(U_o^2 - U_f^2)(W_c + W_t)}{2g\mu(W_t - HL)}$$

which can be solved for the final speed:

$$\frac{U_o^2\left(W_t - HL\right)}{\left(W_c + W_t\right)} = U_o^2 - U_f^2$$

$$U_f^2 = U_o^2\left[1 - \frac{W_t - HL}{W_c + W_t}\right]$$

$$= U_o^2\left[\frac{W_c + HL}{W_c + W_t}\right]$$

Thus the trailer brake test was performed from an initial speed, U_o, down to the final velocity, U_f, given below:

$$U_f = U_o\sqrt{\frac{W_c + HL}{W_c + W_t}}$$

or

$$U_f = U_o\sqrt{1 - \frac{W_t - HL}{W_{cv}}}$$

In all cases U_o was taken as 40 mph.

The brake force performance measure is then computed from the slope of the speed vs. time signal, dU_o/dt, while the brakes were applied.

$$F_b = \left[\frac{W_c + W_t}{g}\right]\frac{dU_o}{dt}$$

Brake-In-Turn

The brake-in-turn test consists of a step brake input during a steady-speed turn.

Specifically, three brake-in-turn procedures were used. These are described below:

a. To provide a steady state 0.3 g cornering level, a 356 ft radius turn was driven at 40 mph. While holding the steering fixed the brake actuator was applied to decelerate the CV at 0.4 g. The trailer brake controller was kept at maximum output adjustment. One left hand and one right hand test were performed.

b. Repeat above, except the brake actuator was set to give deceleration level which would cause incipient lockup of at least one wheel. Again, the trailer brake is set for maximum. One left hand and one right hand test were performed.

c. Repeat b. above, except the trailer brake output was reduced to one half of maximum. This was done by adjusting the electric brake control resistor.

OTHER FIELD TEST MEASUREMENTS

Trailer Yaw Moment of Inertia

To determine the trailer-alone damping and hookup factor it is necessary to measure the trailer yaw moment of inertia. This is readily accomplished with a roller bearing turn table (such as used for wheel alignments), two coil springs, and a stopwatch. The trailer wheels are held off the ground by placing the axle beam on a block, which is positioned on the roller bearing support turntable as shown in Fig. B-6. A counterweight, W_x, is added to balance the trailer hitch load, i.e., $W_t h = W_x \ell_3$. At this condition the trailer floats freely on the turntable with no offset forces.

Two coil springs are attached between the tongue and nearby ground anchor points. A prestretched preload provides a constant spring rate in both directions of travel (since no slack is permitted). The effective spring rate at the hitch (lateral force per foot of deflection) is measured by spring scales with the springs in this prestretched condition.

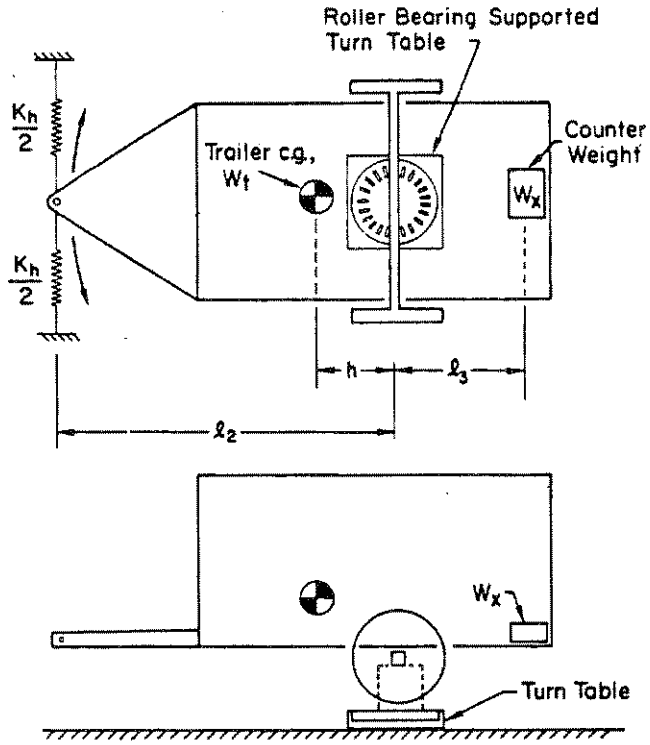


Figure B-6. Test Set-Up for Trailer Moment of Inertia Measurement

The trailer is then gently oscillated (by hand) in the yaw direction (about ±3 in. amplitude), while maintaining the trailer in a level orientation. Elapsed time measurements are taken for 10 full oscillations and then repeated several times to insure consistency. The repeat run frequencies should be in close agreement (3 percent) since damping is very small.

The moment of inertia about the center of rotation is then calculated from the equation:

$$I_1 = \frac{K_h \ell_2^2}{(2\pi f_n)^2}$$

where

K_h = Effective spring rate (lb/ft)

ℓ_2 = Hitch to axle distance (ft)

f_n = Natural frequency (cycles/sec)

This can be converted to the moment of inertia about the c.g., I_{t_o}, and about the hitch point, I_{t_h}, using the parallel axes equations:

$$I_{t_o} = I_1 - \frac{W_t h^2}{g} - \frac{W_x \ell_3^2}{g}$$

$$I_{t_h} = I_{t_o} + \frac{W_t}{g} (\ell_2 - h)^2$$

The inertia values given previously in Vol. II were experimentally determined using the above method.

Surge Brake Gain Measurement

Surge brake gain, G, is defined as the ratio of brake deceleration force developed by the trailer brakes to the horizontal compressive force applied at the trailer ball hitch, i.e., $G = F_{x_b}/F_{x_h}$.

This gain is determined by dynamic straight line brake tests on the trailer alone, which provides data for brake deceleration force, F_{x_b}, versus hydraulic line pressure, B_{t_p}.

Static tests are then performed by applying a horizontal force at the ball hitch, F_{x_h}, and reading the resulting hydraulic line pressure developed, B_{t_p}. The gain is found from the product of the two tests as:

$$G = \frac{F_{x_b}}{B_{t_p}} \times \frac{B_{t_p}}{F_{x_h}}$$

Since the trailer alone straight line brake test has been described previously, only the static test needs further discussion. To accomplish this test, a crank arm (with ball that matches and locks into the hitch ball socket) is used to apply a force to the socket lever arm (see Fig. B-7). Forces are applied to the crank arm in steps starting from zero, going to maximum, and

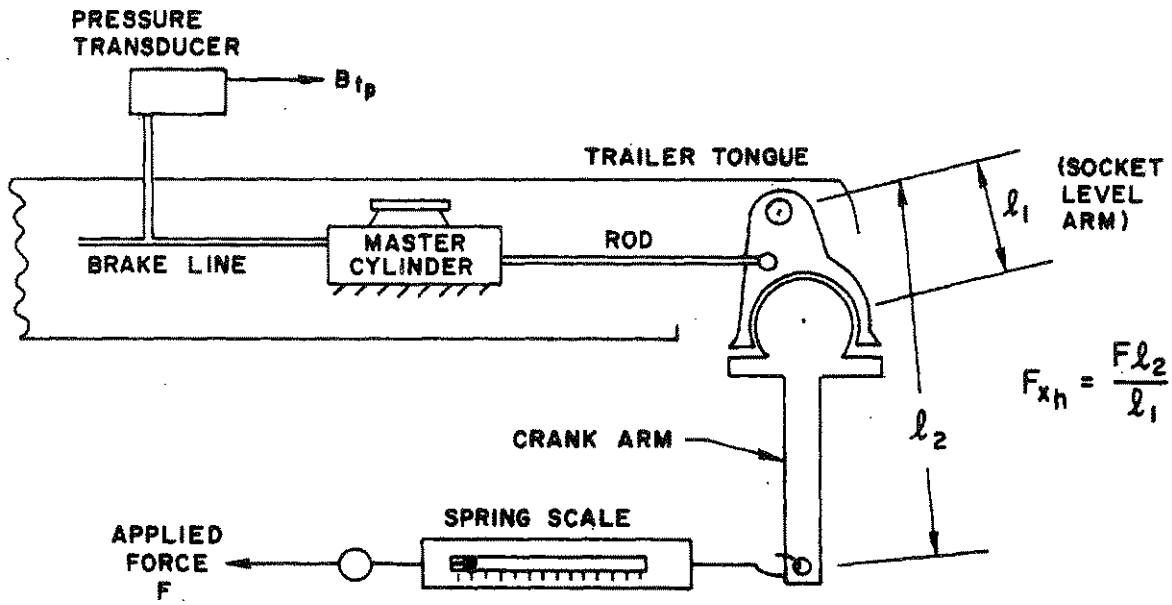


Figure B-7. Static Brake Force Actuator

returning back to zero in gradual steps. The applied force, F, times crank arm distance, ℓ_2, is then equated to the hitch force, F_{x_h}, times its socket lever arm distance, ℓ_1. The brake line pressure is then plotted versus the horizontal hitch force. The slope, B_{t_p}/F_{x_h}, and hysteresis are then obtained from this plot. An example plot is shown in Fig. B-8 for the boat trailer brake.

From trailer alone tests, the horizontal braking force to surge brake pressure, F_{x_b}/B_{t_p}, was found to be equal to 2.0 (see Appendix D), thus the surge brake gain was computed as:

$$G = (2.0)\ \frac{1000}{675} = 3.0$$

TOW CAR/TRAILER SETUP

Procedure for Field Tests

Prior to testing, the following steps were performed for each combination-vehicle.

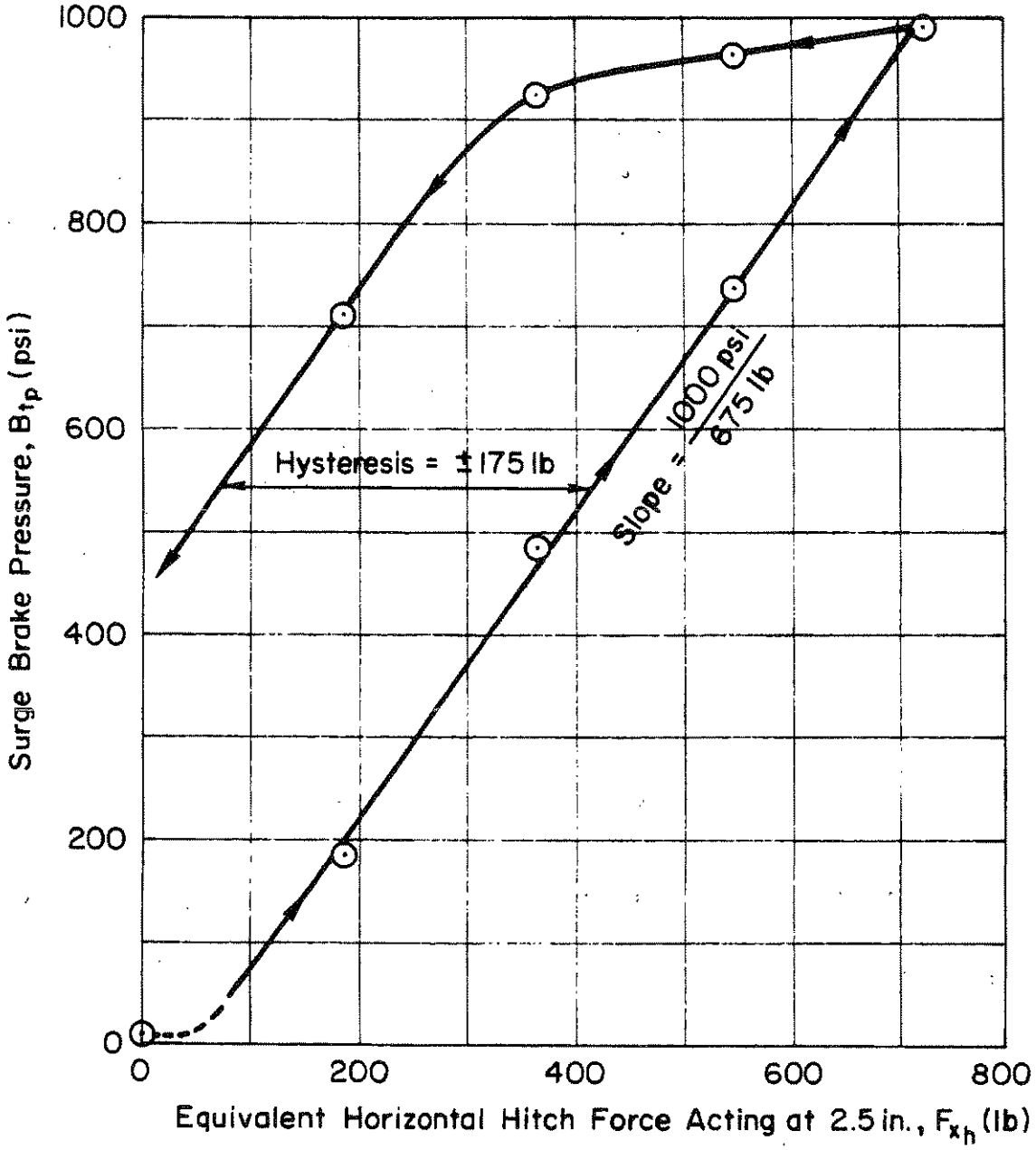


Figure B-8. Test Data for Boat Trailer Surge Brake

1. Load trailer up to desired total weight, W_t.

2. Set and measure desired hitch load with platform scale while trailer is level.

3. Set hitch head height position to match trailer ball socket when trailer is level.

4. Connect trailer to tow car.

5. Relevel tow car by pressurizing air shocks, adding load leveling bars, or both. For load leveling to "+25 percent," chain links are adjusted until front axle of tow car shows more than car alone by 25 percent of the hitch load. For leveling with air shocks, air pressure is added until tow car has same front to rear bumper height differential. If more than maximum pressure is required, the load leveling bars must be used as a supplement. The percent of load leveling in this case will again be the change in the tow car front axle weight (front axle weight with trailer minus front axle weight without trailer) divided by the hitch load.

6. Place CV on individual wheel platform scales and record all weights, including the driver.

7. Record all other data shown on Table B-5.

REFERENCE

B-1. Johnston, Donald E., John W. Zellner, and Irving L. Ashkenas, Handling Test Procedures for Passenger Cars Pulling Trailers. Vol. II: Technical Report, DOT-HS-801-936, June 1976.

TABLE B-5. CAR/TRAILER DATA SHEET

Date:

Tow Car:

Trailer:

Hitch Load (with level trailer):

Load Leveling:

Gas Tank Level:

Test Configuration Number (details such as tire type and pressure, air shocks pressure):

TOW CAR-TRAILER WEIGHTS (INCLUDING DRIVER)

VEHICLE		LEFT	RIGHT	TOTAL
Tow Car	Front			
	Rear			
	Total			
Trailer	Front			
	Rear			
	Total			
CV	Total			

BUMPER HEIGHTS	UP	DOWN
Front		
Rear		
BALL HITCH TO GROUND		

← SUSPENSION HYSTERESIS

LOCATION OF ADDED TEST WEIGHTS IN TRAILER

APPENDIX C

RUN LOG SUMMARY

This appendix contains a complete listing of all tests recorded on FM tape. Table C-1 summarizes the type of conditions and tests performed with all vehicles. Tables C-2 through C-4 then detail the exact run numbers associated with each test. These run numbers can then be associated with tape footage numbers on five FM tapes by reference to the raw run logs kept with the FM tapes. A description of the FM tapes (i.e., sensors, scale factors, center frequency, etc.) was given in Appendix B, Section I.

TABLE C-1. FULL-SCALE TEST SUMMARY

TRAILER	TEST CONFIGURATION				TEST PROCEDURES																				
					SST			CRT			PS			SLB			BIT			BTA			OTHER		
	VGT	HL	LL	AS	C	P	F	C	P	F	C	P	F	C	P	F	C	P	F	C	P	F	C	P	F
U-Haul 5 x 8 (No Brakes)	1500	0	N →	N →							×	×	×				×								
		2-1/2		Y									×												
		5		N Y Y							×	×	×				×								×
		7-1/2		N N Y									×												
		10		N Y Y	×		×	×		×	×	×	×	×	×	×	×		×						
		20		Y →	×			×			×			×			×						×		
Starcraft Starmaster 6 (No Brakes)	1600	0	N →	N →							×	×	×												
		5		Y →	×						×	×	×	×			×								
		10			×			×			×	×	×	×		×	×		×						
		15			×			×			×			×			×								
		20			×			×			×			×			×								
Shasta 17	3000	13	25	N	×			×			×			×			×			×					
			N	Y	×			×			×			×			×								
	3420	5	N	Y		×				×			×												
		7-1/2	N	Y		×							×												
	3880	5	N 20 31	N →				×			×	×	×												
		7-1/2	21										×												
		10	25 35 34		×			×			×	×	×	×		×	×								
		15	23 23			×						×	×		×			×			×			×	
		20	−25	Y	×			×			×			×			×								
		20	+25	N	×			×			×			×			×								
Prowler 22	4000	0	N	N							×														
		5	N N N	Y Y Y		×			×		×	×	×												
		7-1/2	N N	Y Y		×			×			×	×												
		10	N	Y	×			×			×			×			×								
		10	0 −29 0	N Y Y	×	×		×	×		×	×	×	×		×	×			×					
		10	25	N	×			×			×			×			×								
		12-1/2	−6	Y		×			×			×													
		15	−7	Y		×			×			×			×										
		15	17	N		×			×			×			×			×			×			×	
		17-1/2	4	Y		×			×			×													
		20	25	N	×			×			×			×			×								
Holiday Rambler 27	6000	5	N 13	Y N							×	×											×		
		10	−15	Y	×																				
		10	25 15	N N	×	×		×			×	×		×			×			×					
		15	−20	Y	×																				
		15	0	Y	×			×						×			×								
		15	25	N	×			×			×			×			×								
Horse (tandem)	5800	10	LL NOT	Y →	×			×			×									×					
		15	POSSIBLE		×						×														
	4000	5	WITH									×	×												
		10	THIS			×						×	×		×			×			×				
	2000	10	TRAILER								×														
Traveleze 17	4000	5	N 0 N	Y N Y							×	×	×												
		10	N 10 0	Y N Y							×	×	×												
		15	25	N N N	×			×			×			×			×			×					
		15	−32	Y Y Y	×									×			×								
Boat	2275	26	+28	N		×			×															×	
	3000	0	N N N	N N N			×			×	×	×	×												
		3	N	Y									×												
		5	N N N	Y Y Y			×			×	×	×	×												
		5	0	N			×			×			×												
		7-1/2	0	N									×												
		10	N N 32	Y Y N	×		×	×		×	×	×	×	×		×	×		×	×					
		15	N −14	Y Y	×						×			×	×										
		15	25 35 21	N N N	×		×	×		×	×	×	×	×	×										

KEY:

HL = hitch load (percent of trailer weight)
LL = load leveling (percent of hitch load transferred to front axle)
AS = air shocks (Yes if used to level C-V, No if not used)
SST = step steer test (steering set for 0.3 g at 30 mph)
CRT = constant radius turn (400' diameter circle — .3 g at 30 mph)
PS = pulse steer (steer pulse at 55 mph)
SLB = straight line brake (max decel from 40 mph)
BIT = brake in turn (max decel at 0.3 g cornering)
BTA = trailer alone brake capability test
OTHER = misc. tests (calibrations, damping, inertia, braking, etc)
C = Chevrolet Monte Carlo
P = Plymouth Volare
F = Ford Mustang II

TABLE C-2. MONTE CARLO TESTS

Two Car/ Trailer	Test Configuration				Test Procedures/Run No.s						
	Wgt.	Hitch Load	Load Leveling	Air Shocks	SST	CRT	PS	SLB	BIT	BTA	Other
Monte Carlo	4660							1-21			
Pre burn	5270							22-38			
Post burn	5270							39-54			
New switch	5270							55-69			
	4660				72-76	70-71			77-83		
U-Haul AV	1500	10	No	No	95-98	108	84-85	86-93	99-107		
		20	No	Yes	122-126	135-136	109	110-121	127-134		137-140
											153-165
		5	No	No			141		142-147		
		0	No	No			148		149-152		
Starcraft	1600	20	No	Yes	174-179	188	166	167-173	180-187		
		15	No	Yes	212-215	216	189	190-203	204-211		
		10	No	Yes	218-221	237	217	230-236	222-229		
		5	No	Yes	260-264		238-240	241-253	254-259		
		1	No	No			265-268				
Prowler	4000	10	0	No	296-299	316	295	289-294	300-315	269-288	
		10	No	Yes	325-328	338	324	317-323	329-337		
		10	25	No	346-348	355	345	339-344	349-354		
		20	25	No	365-368	373	356-357	359-364	369-372		
		0	No	No			374				
		5	No	Yes			375-377				
Shasta	3000	13	25	No	414-427	428-432	413	398-404	405-412	378-397	
		13	No	Yes	434-447	462	433	456-461	448-454		
	4000	20	-25	Yes	479-497	498-499	463	464-469	470-478		
		20	25	No	509-521	532	500	501-508	522-531		
	3880	10	25	No	548-562	566-568	533	540-547	534-539		
								563-565			
		5	No	No		570	569				
Holiday Rambler	6000	5	No	Yes			571-572				
		10	25	No	602-616 (windy)	617-618	573	585-593	594-601	574-584	
		15	25	No	646-657	660	658-659	619-634	635-645		
		15	0	Yes	677-689	690		661-667	668-676		
		5	No	Yes			691-699				
Rerun		10	25	No	835-847						
		15	-20	Yes	848-861					362	
		10	-15	Yes	877-862					883-392	
Horse	5800	15	No	Yes	702-717		700-701	NP			
		10	No	Yes	725-738	739	718-724	NP			
	2000	9	No	Yes			876				
Traveleze	4000	15	25	No	783-797	798	766-770	759-765	771-782	740-758	
		5	No	Yes			799-802				
		15	-32	Yes	817-830			803-808	809-816		
		10	No	Yes			831-834				
Boat	3000	10	No	Yes	931-940	941	926-927	920-925	928-930	893-919	
		15	No	Yes	949-955		942	943-948			
		15	25	No	964-970	971	956	957-963			
		5	No	Yes			972				
		1/2	No	No			973-975				
Monte Carlo Alone	4000				976-982	983					

TABLE C-3. PLYMOUTH VOLARE TESTS

Tow Car/ Trailer	Test Configuration				Test Procedures/Run Nos.						
	Wgt.	Hitch Load	Load Leveling	Air Shocks	SST	CRT	PST	SLB	BIT	BTA	Other
P Plymouth Volare	4030*				1001-1013 1381-1388	1014		NG 1240-2150	1229-1234		1000 1354
P-3 Prowler	4000	5.	No	Yes	1015-1026	1031	1027-1030				
		7.5	No	Yes	1032-1043	1046	1044-1045				
		10.	-29	Yes	1047-1058	1063-1064	1059-1062				
		12.5	-6	Yes	1065-1075	1079	1076-1078				
		15.	-7	Yes	1080-1089	1091	1090	1205-1210			
		17.5	+4	Yes	1096-1104	1107	1105-1106				
		15.	+17	No	1108-1117	1119	1118	1201-1204	1133-1140	1126-1132b	
					1141-1146 Coast Down	1147-1149 Coast Down					
P-8 Boat	2275	24	+28	No	1165-1175	1176					
					1157-1164 Coast Down			1177-1182			
P-8 Boat	3000	15	+35	No	No		1183	1192-1196			
		15	-14	Yes				1184-1191			
		10	No	Yes			1197				
		5	No	Yes			1198 1199				
		0					1200				
P-6 Horse	4000	10	No	Yes	1275-1288		1274 1289-1293	1251-1256	1257-1264	1265-1273	
		5	No	Yes							
P-4 Shasta	3880	15	+23	No	1330-1342		1329	1294-1299	1300-1307	1308-1328	
					1343-1349 Coast Down						
		10	+35	No			1350				
		5	+21				1351-1352				
P-1 U-Haul	1500	10	No	Yes			1353	1389-1395			
		5	No	Yes			1355				
		0					1356				
P-2 Starcraft	1600	10	No	Yes			1357				
		5	No	Yes			1358				
		0					1359-1360				
P-7 Traveleze	4000	10	+10	No			1361-1363				
		5	No	No			1364				
P-5 Holiday Rambler	6000	10	+15	No			1365-1368				
		5	13	No			1378-1380				

*Test equipment and driver, but no hitch parts.

TABLE C-4

MUSTANG TESTS

Vehicle	Test Configuration				Test Procedures/Run No.s					
	Wgt.	HL	LL	AS	CRT	SST	PS	SLB	BIT	Other
Tow car alone	3315	0			1624	1614-1623		Black-top 1597-1605	1606-1611	Coast down tests 1678
	55/45							Concrete 1679-1681		
Shasta	3420	5	No	Yes	1500	1503-1512	1502			Cal 1501
		7.5	No	Yes		1516-1524	1513-1515			
	3880	5	10	No			1682			
		7.5	7	No			1683-1686			
		10	36	No			1687-1688	1689-1695		Coast down 1696
		15	24	No			1697-1698			1699 free steer pulse
Boat	2950	0	No	No	1537	1527-1536	1525-1526			
		3	No	Yes			1538-1540			
		5	No	Yes	1552	1543-1551	1541-1542			
		5	0%	No	1563	1554-1562	1553			
		7.5	0%	No			1564			
		10	32	No	1568A	1566-1567A	1565	1577-1586	1587-1596	
		15	21	No	1576	1570-1575	1569A			
U-Haul	1500	10	No	Yes	1654	1643-1652	1642	1625-1635	1636-1641	1653 Cal
		7.5	No	Yes			1655			
		5	No	Yes			1656			
		2.5	No	Yes			1657			
		0	No	No			1658-1659			
		5	No	Yes			1660			
Prowler	4000	5	No	Yes			1661			
		7.5	No	Yes			1662			
		10	0%	Yes			1663	1664-1670		
Travel-eze	4000	5	No	Yes			1671			
		10	0%	Yes			1672-1673			
Horse	4000	5	No	Yes			1674-1675			
		10	No	Yes			1676-1677			
Star-craft	1600	0	No	No			1702-1704			
		5	No	Yes			1700-1701			
		10	No	Yes			1721	1705-1714	1715-1720	

APPENDIX D

STRAIGHT LINE BRAKE EQUATIONS AND TEST DATA

STRAIGHT LINE BRAKING EQUATIONS

Insight into the braking behavior of combination vehicles can be obtained from static modeling of the tow car and trailer using the free body diagram sketched in Fig. D-1.

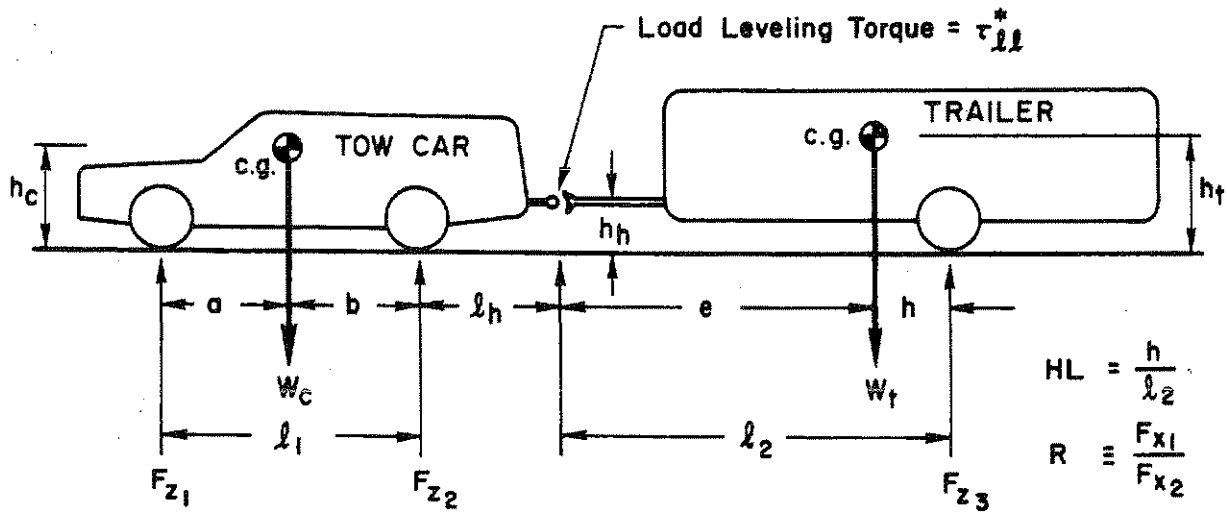


Figure D-1. Static Tow Car/Trailer Braking Model

This includes the effects of weight transfer, and with the auxiliary equations of Ref. D-1 the effects of load leveling on the two vertical loads can also be included.

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* Load leveling torque can be computed from the percent hitch load transferred to the tow car front axle, i.e.,"percent load leveling" as follows:

$$\tau_{\ell\ell} = \left(\frac{\%LI}{100} + \frac{\ell_h}{\ell_1}\right) \frac{HL \cdot \ell_2 \ell_1}{\ell_2 + \ell_h} \quad (\text{ft-lb})$$

Optimum Braking

The longitudinal braking forces at each axle are, ideally, equal to the product of the friction coefficient, μ, and the vertical forces, i.e., $F_{x_i} = \mu F_{z_i}$. However, in order to avoid spinout due to a rear wheel lockup, passenger cars generally have a front brake bias. In this non-optimum case, maximum deceleration is limited by front wheel lockup and hence the rear axle works slightly below capacity. The longitudinal forces are then

$$F_{x_1} = \mu F_{z_1} \tag{D-1}$$

$$F_{x_2} = \frac{F_{x_1}}{R} = \frac{\mu F_{z_1}}{R} \tag{D-2}$$

$$F_{x_3} = \mu F_{z_3} \tag{D-3}$$

where the front to rear tow car brake force proportioning ratio is defined by R. Also, since most large trailers (having eletric brakes) have an adjustable gain to proportion the trailer brakes as a function of tow car brake line pressure, the analysis assumes that the trailer brakes can be adjusted to develop their full braking force. The total deceleration a_x is then:

$$a_x = \frac{F_{x_1} + F_{x_2} + F_{x_3}}{W_c + W_t} \text{ in "g" units} \tag{D-4}$$

Using Fig. D-2, the vertical tire loads, including load leveling, can be derived as:

$$F_{z_1} = \underbrace{\frac{W_c b}{\ell_1}}_{\text{Car Alone}} - \underbrace{\frac{HL\ell_h}{\ell_1}}_{\text{Due to Hitch Load}} + \underbrace{\left[\frac{\ell_2 + \ell_h}{\ell_2 \ell_1}\right] \tau_{\ell\ell}}_{\text{Due to Load Equalization}} + \underbrace{F_{b_1}}_{\text{Dynamic Load Transfer}} \tag{D-5}$$

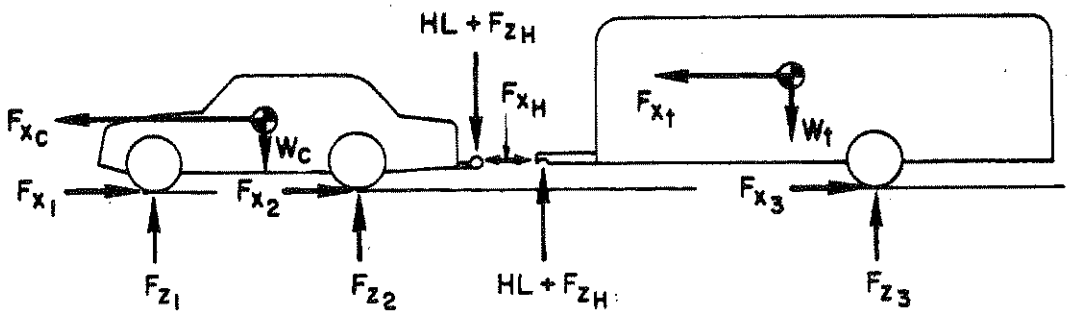


Figure D-2. Dynamic Tow Car/Trailer Braking Forces

$$F_{z_2} = \frac{W_c a}{\ell_1} + \frac{HL\left(\ell_1 + \ell_h\right)}{\ell_1} - \left[\frac{\ell_1 + \ell_h + \ell_2}{\ell_2 \ell_1}\right] \tau_{\ell\ell} + F_{b_2} \tag{D-6}$$

$$F_{z_3} = W_t - HL + \frac{\tau_{\ell\ell}}{\ell_2} + F_{b_3} \tag{D-7}$$

where the dynamic load transfers are

$$F_{b_1} = \frac{a_x W_c h_c}{\ell_1} - \frac{F_{z_h} \ell_h}{\ell_1} + \frac{F_{x_h} h_h}{\ell_1} \tag{D-8}$$

$$F_{b_2} = -\frac{a_x W_c h_c}{\ell_1} + \frac{F_{z_h}\left(\ell_h + \ell_1\right)}{\ell_1} - \frac{F_{x_h} h_h}{\ell_1} \tag{D-9}$$

$$F_{b_3} = \underbrace{-\frac{a_x W_t \left[h_t - h_h\right]}{\ell_2}}_{\text{vehicle mass effect}} \underbrace{- \frac{\mu F_{z_3} h_h}{\ell_2}}_{\text{hitch forces}} \tag{D-10}$$

also

$$F_{z_h} = -F_{b_3} \qquad \left(\begin{array}{l}\text{Trailer dynamic}\\ \text{load transfer}\\ \text{onto tow car}\end{array}\right) \tag{D-11}$$

$$F_{x_h} = a_x W_t - \mu F_{z_3} \qquad \left(\begin{array}{l}\text{Trailer deceleration}\\ \text{force passed onto}\\ \text{tow car}\end{array}\right) \tag{D-12}$$

These 12 equations can be combined as follows:

$$F_{x_1} + F_{x_2} + F_{x_3} = \mu F_{z_1} + \frac{\mu F_{z_1}}{R} + \mu F_{z_3} = \left[\left(\frac{R + 1}{R}\right)F_{z_1} + F_{z_3}\right]\mu$$

Therefore,

$$a_x = \frac{\left[\left(\frac{R + 1}{R}\right)F_{z_1} + F_{z_3}\right]\mu}{W_c + W_t} \tag{D-13}$$

Also,

$$F_{b_1} = \frac{a_x W_c h_c}{\ell_1} - \frac{\ell_h}{\ell_1}\left[\frac{a_x W_t (h_t - h_h)}{\ell_2} + \frac{\mu F_{z_3} h_h}{\ell_2}\right] + \frac{h_h}{\ell_1}\left[a_x W_t - \mu F_{z_3}\right]$$

$$F_{b_2} = -\frac{a_x W_c h_c}{\ell_1} + \left[\frac{\ell_h + \ell_1}{\ell_1}\right]\left[\frac{a_x W_t (h_t - h_h)}{\ell_2} + \frac{\mu F_{z_3} h_h}{\ell_2}\right] - \frac{h_h}{\ell_1}\left[a_x W_t - \mu F_{z_3}\right]$$

and

$$F_{z_3} = W_t - HL + \frac{\tau_{\ell\ell}}{\ell_2} - \frac{a_x W_t (h_t - h_h)}{\ell_2} - \frac{\mu F_{z_3} h_h}{\ell_2}$$

Therefore, solving for F_{z_3},

$$F_{z_3} = \frac{\ell_2 W_t - \ell_2 HL + \tau_{\ell\ell} - a_x W_t (h_t - h_h)}{\ell_2 + \mu h_h} \tag{D-14}$$

Also,

$$F_{z_1} = \frac{W_c b}{\ell_1} - \frac{HL\ell_h}{\ell_1} + \left[\frac{\ell_2 + \ell_h}{\ell_2 \ell_1}\right]\tau_{\ell\ell} + \frac{a_x W_c h_c}{\ell_1}$$

$$- \frac{\ell_h a_x W_t (h_t - h_h)}{\ell_1 \ell_2} + \frac{h_h a_x W_t}{\ell_1}$$

$$+ \left[\frac{\ell_2 W_t - \ell_2 HL + \tau_{\ell\ell} - a_x W_t (h_t - h_h)}{\ell_2 + \mu h_h}\right]\left[- \frac{\ell_h \mu h_h}{\ell_1 \ell_2} - \frac{\mu h_h}{\ell_1}\right] \quad \text{(D-15)}$$

and,

$$F_{z_2} = \frac{W_c a}{\ell_1} + \frac{HL(\ell_1 + \ell_h)}{\ell_1} - \left[\frac{\ell_1 + \ell_h + \ell_2}{\ell_2 \ell_1}\right]\tau_{\ell\ell} - \frac{a_x W_c h_c}{\ell_1}$$

$$+ \frac{(\ell_h + \ell_1) a_x W_t (h_t - h_h)}{\ell_1 \ell_2} - \frac{h_h a_x W_t}{\ell_1}$$

$$+ \left[\frac{\ell_2 W_t - \ell_2 HL + \tau_{\ell\ell} - a_x W_t (h_t - h_h)}{\ell_2 + \mu h_h}\right]\left[\frac{(\ell_h + \ell_1)\mu h_h}{\ell_1 \ell_2} + \frac{h_h \mu}{\ell_1}\right] \quad \text{(D-16)}$$

For front wheel lockup, Eqs. 13-15 can be solved for a_x.

For example, the case of no load leveling, $\tau_{\ell\ell} = 0$, results in a CV deceleration given by Eq. 17 below.

$$a_{x_{cv}} = \frac{\dfrac{W_c b}{\ell_1} - \dfrac{HL\ell_h}{\ell_1} + \left[\dfrac{W_t \ell_2 - HL\ell_2}{\ell_2 + \mu h_h}\right]\left[\dfrac{R}{R+1} - \dfrac{\ell_h h_h \mu}{\ell_1 \ell_2} - \dfrac{h_h}{\ell_1}\mu\right]}{\dfrac{(W_c + W_t)R}{\mu(R+1)} - \dfrac{W_c h_c}{\ell_1} - \dfrac{W_t h_t}{\ell_1} + \dfrac{W_t [h_t - h_h]}{\ell_2 + \mu h_h}\left[\dfrac{R}{R+1} + \dfrac{\ell_h}{\ell_1} - \dfrac{h_h \mu}{\ell_1}\right]} \quad \text{(D-17)}$$

For tow car rear axle lockup,

$$F_{x_2} = \mu F_{z_2}$$

$$F_{x_1} = R F_{x_2} = R\mu F_{z_2}$$

In this case

$$a_x = \frac{R\mu F_{z2} + \mu F_{z2} + \mu F_{z3}}{W_c + W_t}$$

$$a_x = \frac{\mu(R + 1)F_{z2} + \mu F_{z3}}{W_c + W_t} \qquad \text{(D-18)}$$

and Eqs. 14, 16, and 18 can be solved for a_x.

Equations 13, 14, and 15 or 14, 16, and 18 can readily be implemented on a hand calculator to derive a complete CV brake performance map such as illustrated in Fig. D-3. The intersection of front and rear lockup conditions represents optimum braking of all axles, $a_x = \mu$.

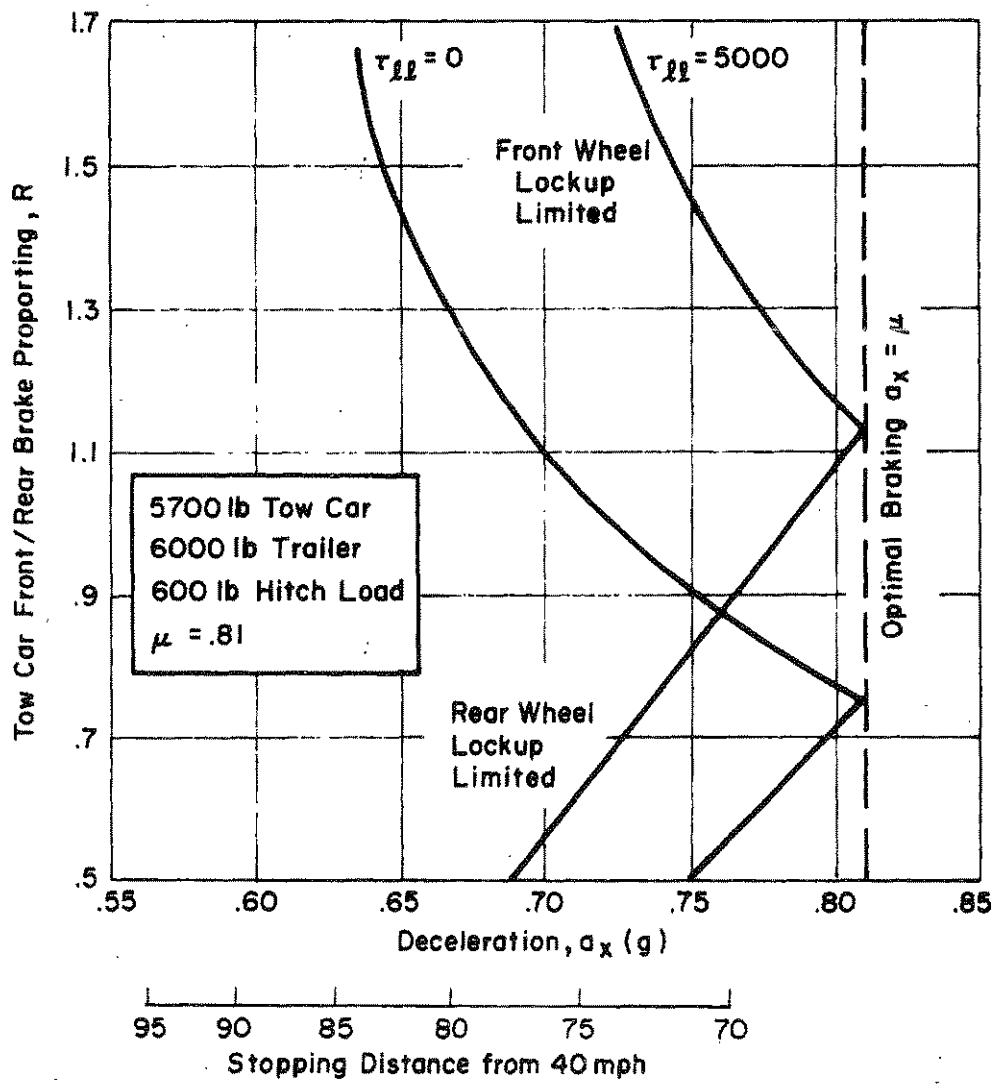


Figure D-3. Analytical Combination-Vehicle Brake Performance Map

Non-Optimum Trailer Braking

For the case of non-optimum trailer braking the trailer brake force F_{x_3} is defined as the trailer alone deceleration limit, $a_{x_{TA}}$, times the static axle weight, i.e., total trailer weight minus hitch load. The three braking forces are then:

$$F_{x_1} = \mu F_{z_1}$$

$$F_{x_2} = \frac{\mu F_{z_1}}{R}$$

$$F_{x_3} = a_{x_{TA}} (W_t - HL)$$

In this case only the vertical tire force F_{z_1} need be derived as a function of the combination vehicle deceleration, $a_{x_{cv}}$, i.e.,

$$F_{z_1} = \frac{W_c b}{\ell_1} - \frac{HL\ell_h}{\ell_1} + \frac{a_{x_{cv}} W_c h_c}{\ell_1} + \frac{F_{b_3}\ell_h}{\ell_1} + \frac{h_h)}{\ell_1}\left[a_{x_{cv}} W_t - a_{x_{TA}}\left(W_t - HL\right)\right]$$

$$F_{b_3} = -\frac{a_{x_{cv}} W_t (h_t - h_h)}{\ell_2} - \frac{h_h a_{x_{TA}} (W_t - HL)}{\ell_2}$$

This is identical to Eq. D-5 with the revised definition for F_{x_3} and no load leveling

STRAIGHT LINE BRAKE TEST DATA

Table D-1 presents all tow vehicle alone and combination vehicle data. Figures D-4 through D-9 present the trailer alone brake capability plots.

TABLE D-1. STRAIGHT LINE BRAKING

Run No.	Tow Veh.	Trailer	Weight	Conditions: Hitch Load	Conditions: Load Leveling	Pedal Force	Lock-up	Stopping Dist. from 40 mph	Avg ± Std Dev.
1	Monte Carlo	None	4660 Pre-B			36-40	No	80.5	80.1 ± 1.15
2								79.6	
3								79.1	
4								80.1	
5								79.0	
6								82.1	
7						45	BR	73.8	71.9 ± 1.13
8								71.2	
9								71.9	
10								70.5	
11								72.4	
12								71.6	
13						30	No	89.9	89.6 ± 1.04
14								90.4	
15								88.4	
16								86.5	
17						22.5	No	120	
18						17.5	No	163	158 ± 7.07
19								153	
20							No	179.2	65 mph / 60 mph: 176.5 ± 3.75
21							No	173.9	
22			5270 Pre-B					Abort	
23						65	RF	79.7	78.7 ± 1.48
24						55	RF	77.6	
25						40	RF at 20	76.6	77.7 ± 1.73
26							No	75.3	
27							RF at 25	80.2	
28							RF at 30	78.5	
29							RF at 30	78.6	
30							RF at 10	77.1	
31						60	BF	73.2	75.0 ± 2.04
32								72.8	
33								76.9	
34								76.0	
35								73.6	
36								77.5	
37							BF	170.9	58 mph / 59 mph: 162.3 ± 12.2
38							No	153.7	
39			5270 Post-B			50	No	78.9	78.1 ± 0.76
40								77.5	
41								77.7	
42								77.6	
43								79.2	
44								77.6	
45						68	No	74.3	77.2 ± 4.08
46						75	BF	82.9	
47							No	77.2	
48						82.5	No	74.2	
49						90	No	70.9	73.4 ± 2.28
50							No	76.4	
51							BF	72.8	
52							No	73.3	
53							BF	172.1	57 mph / 59 mph: 167.9 ± 6.01
54							No	163.6	
55						45	No	85.2	New stop switch
56								76.9	79.0 ± 2.83
57								79.0	
58								78.2	
59								78.9	
60								77.4	
61								77.6	
62						46		170.3	60 mph -

TABLE D-1 (Continued)

Run No.	Tow Veh.	Trailer	Weight	Conditions: Hitch Load	Conditions: Load Leveling	Pedal Force	Lock-up	Stopping Dist. from 40 mph	Avg ± Std Dev.
63	Monte Carlo	None	5270 Post-B			78	BF	76.6	73.7 ± 2.64
64							No	70.7	
65							No	70.6	
66							RF	73.7	
67							BF	76.4	
68							RF	74.4	
69							BF	171.2	60 mph -
86	Monte Carlo	U-Haul	1500	10	No	45	BF	94.9	92.9 ± 1.94
87						43	BF	99.8	
88						35	No	96.1	
89								93.3	
90								90.9	
91								91.0	
92								92.4	
93								93.7	
110			1500	20	No			Abort	
111						40	No	92.1	
112						40	BF at 20	94.8	
113						40	BF	101.1	
114			1500	20	No	33	No	98.9	96.7 ± 5.02
115								104	
116								95.4	
117								93.5	
118								99.0	
119								88.1	
120								Abort	
121								98.1	
167	Monte Carlo	Star-Craft	1600	20	No	43	BF	107.1	
168						40	LF	102.1	101 ± 1.99
169							BF at 10	99.8	
170							No	99.9	
171							BF	104.4	
172			95.5 ± 3.76 (no lockup) runs			35	No	92.8	93.5 ± 0.99
173						35	No	94.2	
									98.8 ± 4.4
190			1600	15	No	43	?	104.0	98.6 ± 5.01
191						43	?	106.3	
192						35	?	108.3	
193							?	104.4	
194							?	98.9	
195							?	96.0	
196								Abort	
197								95.3	
198								96.1	
199								Abort	
200							No	92.9	
201							No	92.4	
202							No	100.1	
203							No	101.6	
230			1600	10	No	40	No	107.7	106 ± 1.51
231								107.1	
232								104.5	
233								104.8	
234								104.6	
235								103.8	
236								Abort	

TABLE D-1 (Continued)

Run No.	Tow Veh.	Trailer	Weight	Conditions: Hitch Load	Conditions: Load Leveling	Pedal Force	Lock-up	Stopping Dist. from 40 mph	Avg ± Std Dev.
241	Monte Carlo	Star-craft	1600	5	No	43	BF	100	
242						43	BF	101.1	
243						40	BF	99.2	
244						37	No	100	
245								95.5	
246								97.2	
247								98.3	
248							RF at 20	103.2	
249							RF at 10	95.6	99.6 ± 2.93
250							No	100.0	(100. ± 2.1 with no lockups)
251								100	
252								102.0	
253								104.0	
398	Monte Carlo	Shasta	3000	13	25	37	No	87.0	
399					88.3 ± 1.3	37	No	88.2	
400						37	No	89.6	
401						37	LF_T Inc.	85.2	86.7 ± 2.49
402						37	BF_T	85.6	
403						37	BF_c, RF_T	82.4	
404						40	BF_c	88.8	
456					No	40	BF_c	97.2	
457						35	BF_c	101.0	
458						32	BF_c	104.7	
457A						30	No	97.2	98.5 ± 3.45
458A						28	LF_T at 10	94.5	
459						28	LF_T at 10	97.8	
460						28	LF_T at 10	96.7	
464			4000	20	-25	32	No	93.3	
465							No	98.5	
466							RF_c	101.2	
467							RF_c	97.6	98.7 ± 4.45
468							BF_c	95.5	
469							BF_c	106	
501			4000	20	25	35	BF_c	101.5	
502							BF_c	107	
503							BF_c	108	105 ± 3.51
504							RF_c at 10	101	
505						30	No	98.2	101.0 ± 4.4
506							RF at 10	97	
507							RF at 10	97.9	97.6 ± 0.57
508							RF at 10	97.2	
540			4000	10	25	37	BF_c	112	
541						27	No	123	
542						30	BF_c	120	Max Resistor
543						27	RF_c	115	
544						27	RF_c	109	
545							RF_c	105	
546							RF_c	105	106 ± 2
547							RF_c	105	
563			4000	10	25	33	No	108	
564						35	RF at 10	99.8	
565A						37	BF_c	97.7	101.3 ± 4.58
565B						37	BF_c	99.6	
759	Monte Carlo	Travel-Eze	4000	15	25	25	No	110	Press. too low
760						32	LF_T	96.9	
761						32	LF_T	95.3	
762						32	LF_T 108	92.7	94.4 ± 1.90
763						35	LF_T, RF_c	92.3	
764						38	LF_T, BF_c	94.6	
765						25	No	105	Press. too low
803			4000	15	-32	30	LF_T	91.7	
804						33	BF_T	90.9	
805						32	BF_T	92.2	
806						32	BF_T, LF_c	92.2	91.8 ± 0.64
807						30	BF_T, LF_c	92.6	
808						30	BF_T, BF_c	91.3	

TABLE D-1 (Continued)

Run No.	Tow Veh.	Trailer	Weight	Conditions: Hitch Load	Conditions: Load Leveling	Pedal Force	Lock-up	Stopping Dist. from 40 mph	Avg ± Std Dev.
289	Monte Carlo	Prowler	4000	10	0%	38	LF_T at 20	96	95.6 ± 2.98
290							LF nibble	95.3	
291								97.0	
292								97.3	
293							LF at 10	98.0	
294								89.8	
317			4000	10	No	40	No	92.8	93.6 ± 2.90
318							No	89.8	
319						92.3 ± 1.8 (No Lock-up)	LF_c	95.2	
320							No	94.8	
321							No	92.7	
322							No	91.5	
323							LF_c	98.7	
339			4000	10	25	37	LF_T	93.3	87.3 ± 3.49
340								87.3	
341								86.4	
342								88.5	
343								84.6	
344								83.4	
358			4000	20	25		No	89.3	90.3 ± 2.90
359							No	94.3	
360							No	88.7	
361							BF_c	94.5	
362							RF_c, LF_T	88.5	
363							BF_c, LF_T	87.2	
364							BF_c, LF_T	89.8	
585	Monte Carlo	Holiday Rambler	6000	10	25	32	No	124	Press. Too Low
586						35	No	118	
587						35	No	111	112 ± 4.07
588						40	BF_c	109	
589						37	LF_c	108	
590						40	BF_c	108	
591						40	BF_c	115	
592						35	BF at 20	110	
593						37	BF_c	117	
619			6000	15	25	35	No	106	104.5 ± 2.90
620						37	No	106	
621							No	103	
622							LF_c	105	
623							LF_c at 20	98.7	
624							BF_c	108	
625							BF_c	106	
626						35	BF_c	107	
627							RF_c at 15	106	
628							RF_c inc.	104	
629							RF_c at 15	100	
630								Abort	
631								Abort	
632								Abort	
633						30	No	104	Too low press.
634						25	No	113	
661			6000	15	0	28	No	125	Press. too low
662						32	No	112	113.5 ± 4.04
663						30	No	115	
664						35	BF_c	112	
665						32	BF_c	121	
666						30	No	110	
667						30	BF_c	111	
920	Monte Carlo	Boat	3000	10	10	30	No	102	95.8 ± 4.58
921						32	No	99.4	
922					97.7 ± 6.2 (No Lock-Up)	32	LF_c	96.7	
923						32	LF_c	95.5	
924						32	LF_c, LF_T @ 15	91.3	
925						30	No	90.1	
943			3000	15	No	25	No	121	Press. Too Low
944						35	BF_c	102	102 ± 3.68
945						32	BF_c	107	
946						27	No	104	
947						30	BF_c	102	
948						30	BF_c, RF_T	96.9	

TABLE D-1 (Continued)

Run No.	Tow Veh.	Trailer	Weight	Conditions		Pedal Force	Lock-up	Stopping Dist. from 40 mph	Avg ± Std Dev.
				Hitch Load	Load Leveling				
957	Monte Carlo	Boat	3000	15	25	30	No	131	Brakes cold
958						27	No	102	
959						37	BF_c	106	
960						37	BF_c	107	106 ± 2.56
961						33	BF_c	110	
962						32	BF_c	106	
963						25	BF_c at 10	106	
1213	Volare Alone	None	4030						
1214									
1215									
1216									
1217									No good. Fifth wheel not on ground
1218									
1219									
1220									
1221									
1222									
1223									
1224									
1240						107	No	69.0	
1241					—	110	RR at 15	70.3	
1242								Abort	71.2 ± 1.99
1243						115	BF, LR	73.6	
1244						115	LF, RR	71.9	
1245						100	No	76.3	
1246						87	No	85.4	Individual points
1247						80	No	81.8	at decreasing
1248						63	No	105.	pedal forces
1249						50	No	146.	
1250						77	No	88	
1294	Volare	Shasta	3880	15	23			Abort	
1295						85	No	102	Press too low
1296						93	No	93.3	
1297						96	LF_c	91.3	91.8 ± 1.04
1298						98	LF_c	91.0	
1299						95	No	91.5	
1389	Volare	U-Haul	1500	10	No			Abort	
1390						95	No	99.5	
1391						100	BF_c	109	
1392						100	LF_c	101	
1393						96	LF_c at 10	99.8	102.1 ± 3.77
1394						90	No	99.5	
1395						92	No	104.	
1201	Volare	Prowler	4000	15	max	107	BF_c, BR_T, RF_T	80.0	
1202						105	LF_c, BR_T	82.3	83.3 ± 3.18
1203						100	BR_T, RF_T	83.2	
1204						95	BR_T	87.6	
1205				15	min	95	LF_T incip	85.7	
1206						93	LF_T incip	88.3	
1207						99	LF_T	83.8	84.7 ± 1.96
1208						100	LF_T	83.8	
1209						110	LF_T, LF_c	83.4	
1210						110	LF_T, LF_c	83.3	
1177	Volare	Boat	3000	15	-14	46	No	201	
1178						55		191	Individual points
1179								Abort	at increasing
1180						60		190	pressures
1181						75	No	144	
1182						80		131	
1192						105	No	97.1	
1193						107	No	87.5	
1194						115	LF_c	83.4	88.8 ± 5.03
1195						107	No	87.6	
1196						107	LF_c	88.6	

TABLE D-1 (Continued)

Run No.	Tow Veh.	Trailer	Weight	Conditions: Hitch Load	Conditions: Load Leveling	Pedal Force	Lock-up	Stopping Dist. from 40 mph	Avg ± Std Dev.
1184	Volare	Boat	3000	15	7.5%			Abort	Press. Too Low
1185						90	No	105	
1186						90	No	106	
1187						92	No	98.6	
1188						96	No	93.9	92.4 ± 5.21
1189						102	No	90.9	
1190						105	No	Abort	
1191						115	BF_c, RF_T	86.2	
1251	Volare	Horse	4000	10	No	90	LF_c, BR_T	113.	
1252.						83	BR_T	116	
1253						82	LR_T	113	115. ± 2.14
1254						82	BR_T	113	
1255						80	BR_T	116	
1256						75	BR_T	118	
1597	Mustang Alone	None	3315			60	RR solid	72.6	
1598						60	LF solid	74.0	
1599						45	No	83.3	76.5 ± 3.74
1600						50	No	75.3	
1601						50	No	76.5	
1602						52	LF	77.3	
1603						37	No	103.5	Decreasing Pressures
1604						25	No	128.0	
1605				BLACK TOP		18	No	236.	
1679						?	No	86.8	
1680						?	LR incip	76.8	81.6 ± 5.01
1681				CONCRETE		?	RF, LR	81.3	
1625	Mustang	U-Haul	1500	10	No	52	No	106	Press. Too Low
1626						55	No	102	
1627						62	No	99.2	
1628						67	RF_c	99.1	
1629						66	RF_c	104	
1630						62	RF_c	109	103.7 ± 3.40
1631						62	RF_c	105	
1632						52	No	Abort	
1633						59	RF_c	105	
1634						55	RF_c	106	
1635						49	No	109	
1664	Mustang	Prowler	4000	10	0	55	No	89.6	Press. too low
1665						60	BF_T	88.0	
1666						63	BF_T, RF_c	86.7	
1667						67	BF_T, RF_c	91.3	90.8 ± 3.23
1668						60	BF_T	89.8	
1669						63	BF_T, RF_c	94.8	
1670						58	BF_T, RF_c	94.0	
1705	Mustang	Star-craft	1600	10	No	50	No	107	
1706						58	No	108	
1707						55	No	107	
1708						57	No	104	
1709				108 No lockup		57	LF_c	115	109.5 ± 3.98
1710						56	LF_c	114	
1711						50	No	109	
1712						55	LF_c	112	
1713						52	No	114	
1714						52	No	105	
1689	Mustang	Shasta	3880	10	?	60	No	Not rec.	
1690						65	No	102.	
1691						67	No	Not rec.	
1692						68	RF_c	111	108.2 ± 3.83
1693						68	RF_c	107	
1694						68	RF_c	111	
1695						65	No	110	

TABLE D-1 (Concluded)

Run No.	Tow Veh.	Trailer	Weight	Conditions		Pedal Force	Lock-up	Stopping Dist. from 40 mph	Avg ± Std Dev.
				Hitch Load	Load Leveling				
1577	Mustang	Boat	2950	10	32	55	No	99.9	109.1 ± 3.98
1578						60	RF_c	110	
1579						55	No	111	
1580						57	No	107	
1581						60	No	109	
1582						62	No	110	
1583						65	No	107	
1584						70	RF_c	110	
1585						65	RF_c	112	
1586						62	RF_c	115	

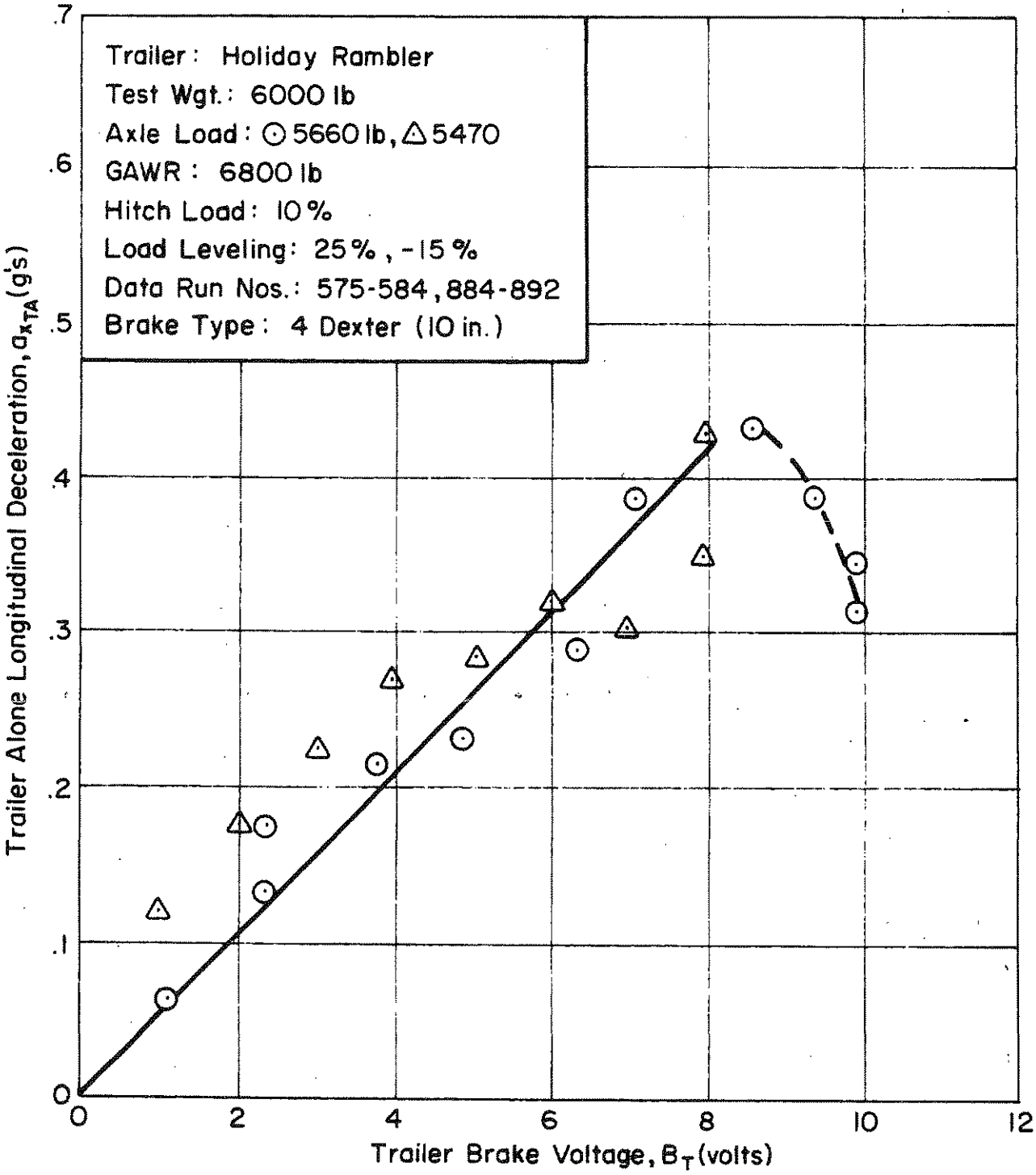


Figure D-4. Electric Brake Gain for 27 ft Travel Trailer

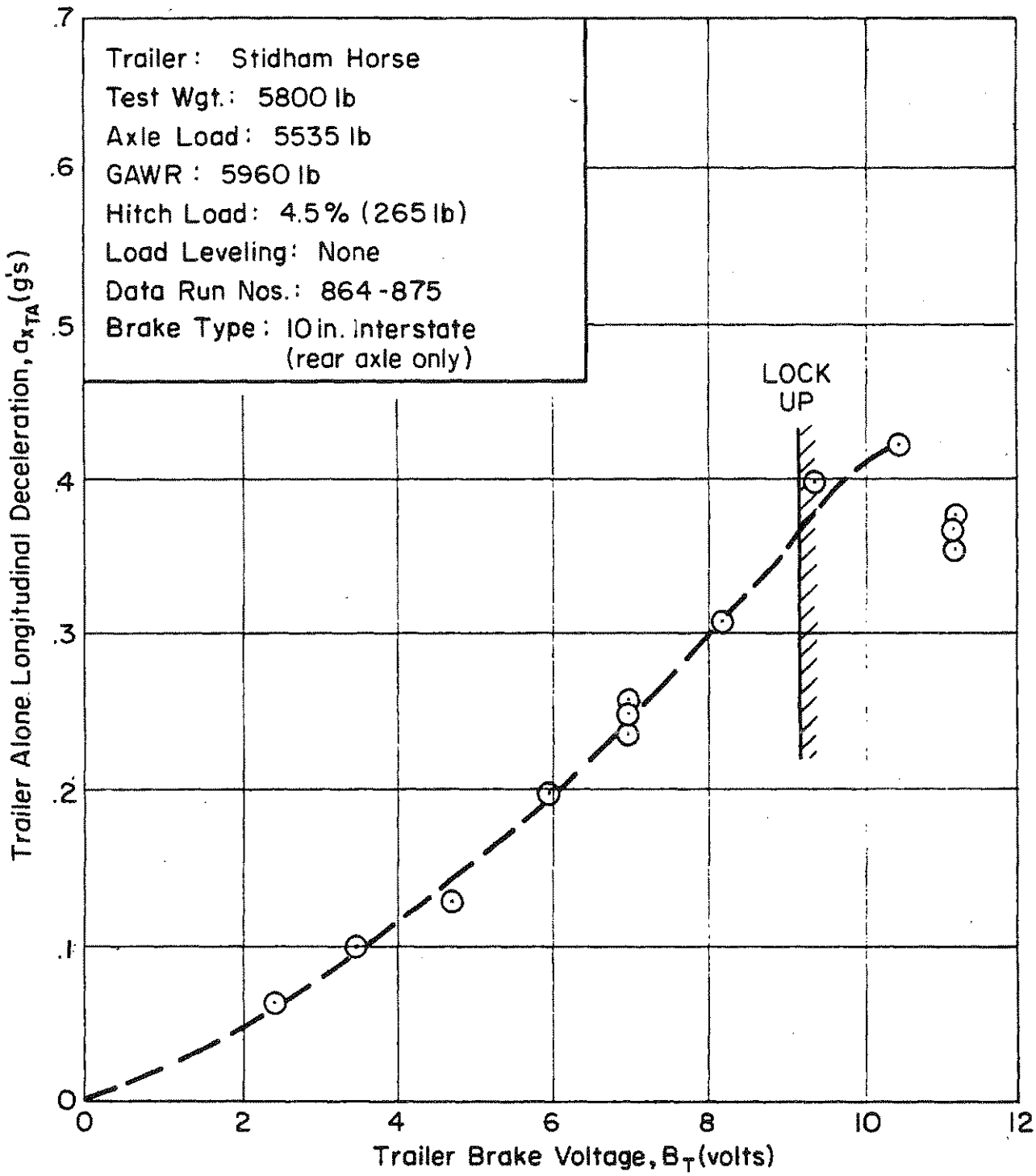


Figure D-5. Electric Brake Gain for Horse Trailer

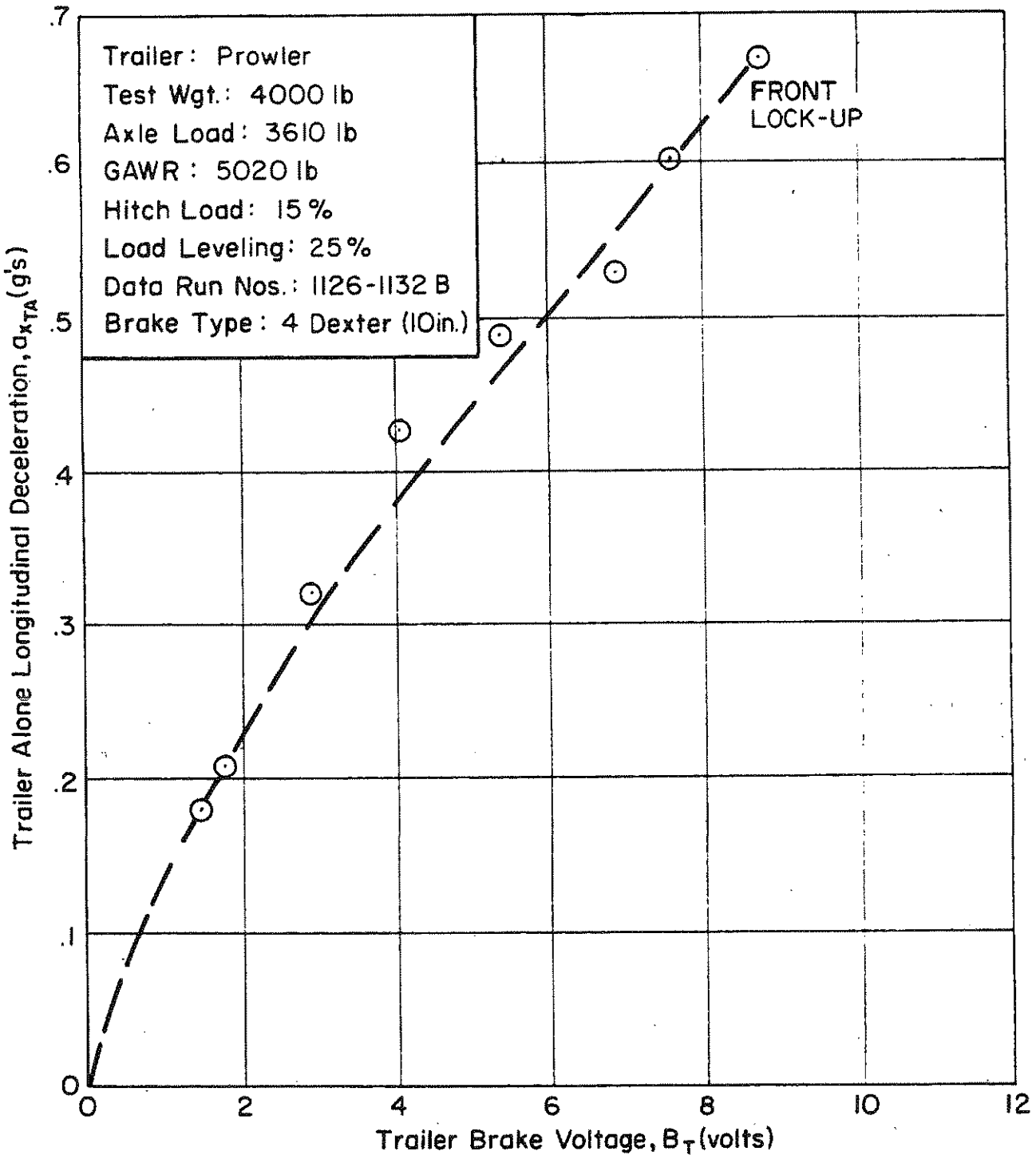


Figure D-6. Electric Brake Gain for 22 ft Travel Trailer

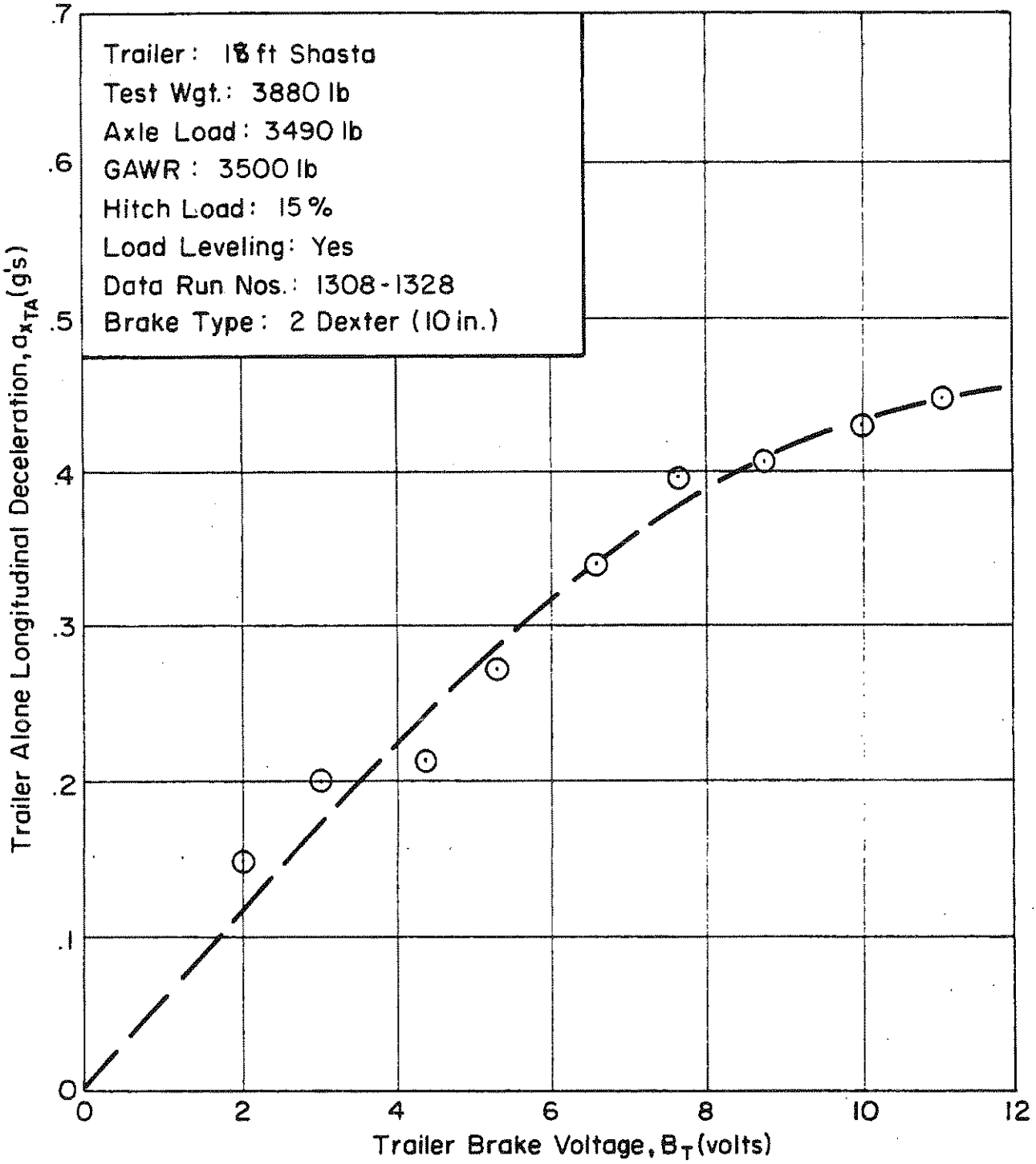


Figure D-7. Electric Brake Gain for 18 ft Travel Trailer

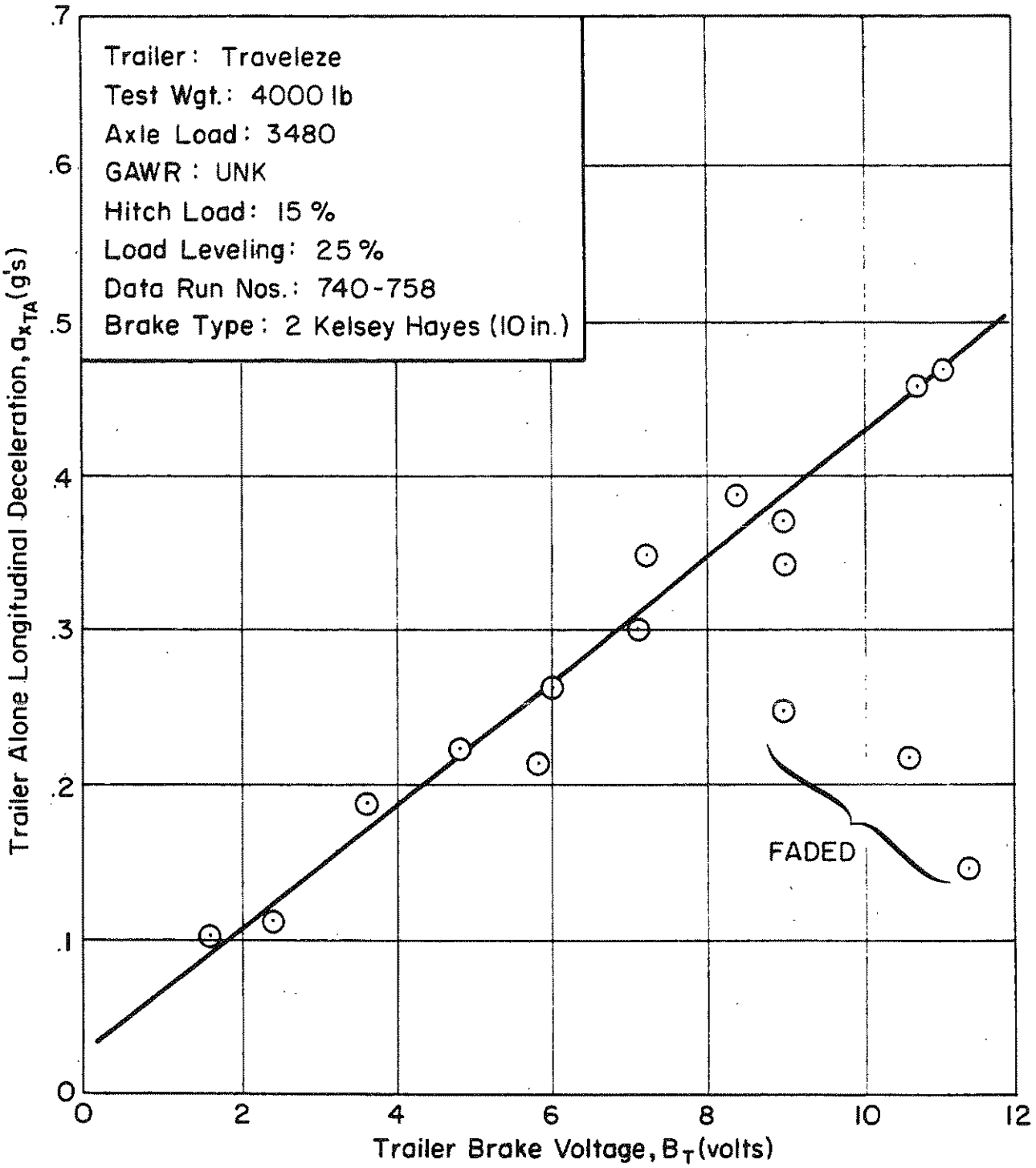


Figure D-8. Electric Brake Gain for 19 ft Travel Trailer

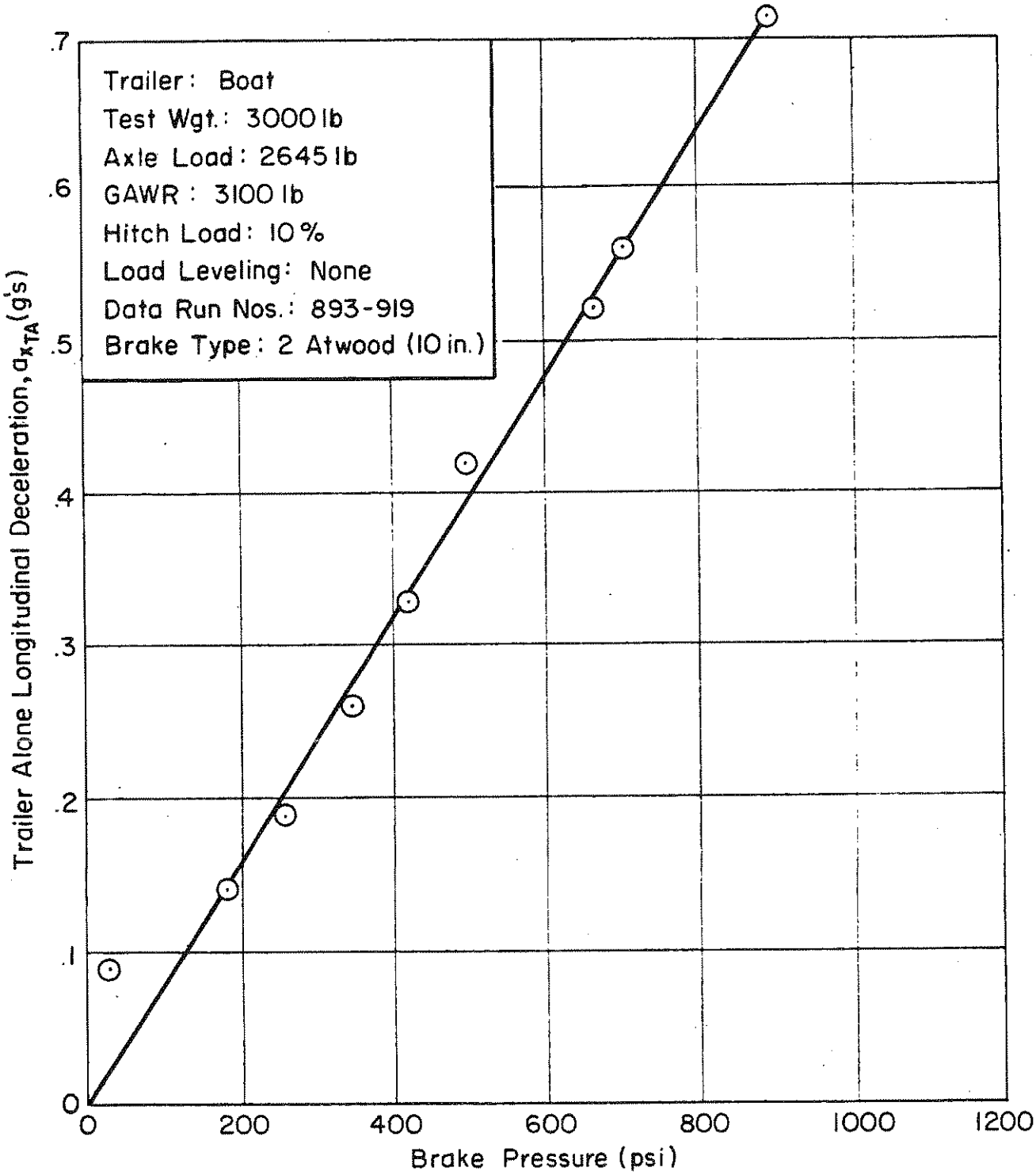


Figure D-9. Brake Gain for Surge Braked Trailer

REFERENCES

D-1 Klein, Richard H., and Henry T. Szostak, Effects of Weight Distributing Hitch Torque on Car-Trailer Directional Control and Braking, NHTSA DOT HS-803 248, October 1977.

APPENDIX E

TRAILER DAMPING RATIO DATA

Presented in this appendix are the damping ratio results from the pulse steer test procedure for all combination-vehicles.

One strip chart trace for each CV is also included. Each of these strip chart records show the pulse steer input, the trailer hitch angle response, the CV setup conditions, and the damping ratio, ζ_η, and frequency, ω_η (rad/sec), which were optimally fit to that particular run over the 2 sec time interval indicated. Since four repeat runs were made, the average damping ratio and speed are also given below each figure. It should be noted that in all cases the damping test was not necessarily performed at the specified 55 mph speed. In these cases the trailer damping ratio versus speed relationship shown in Fig. E-1 was used to correct each data point to the 55 mph damping ratio value shown in Table E-1. The strip chart records are presented in Fig. E-2 for the intermediate tow car, Fig. E-3 for the compact, and Fig. E-4 for the subcompact.

Unwanted trailer swing may also occur while in a steady state turn such as experienced on a curving road. This non-zero lateral acceleration condition is a significant factor because the speed at which swing damping goes to zero is much lower. This effect is related to the reduction in trailer tire cornering as cornering forces are increased. For example, at 0.4 g lateral acceleration, the trailer tire cornering stiffness could be reduced by as much as 50 percent. This would reduce the speed for zero damping to about 70 percent of that in a straight ahead condition.

Examples of reduced trailer damping due to steady state cornering at high lateral acceleration levels are presented in Fig. E-2 and summarized in Table E-2.

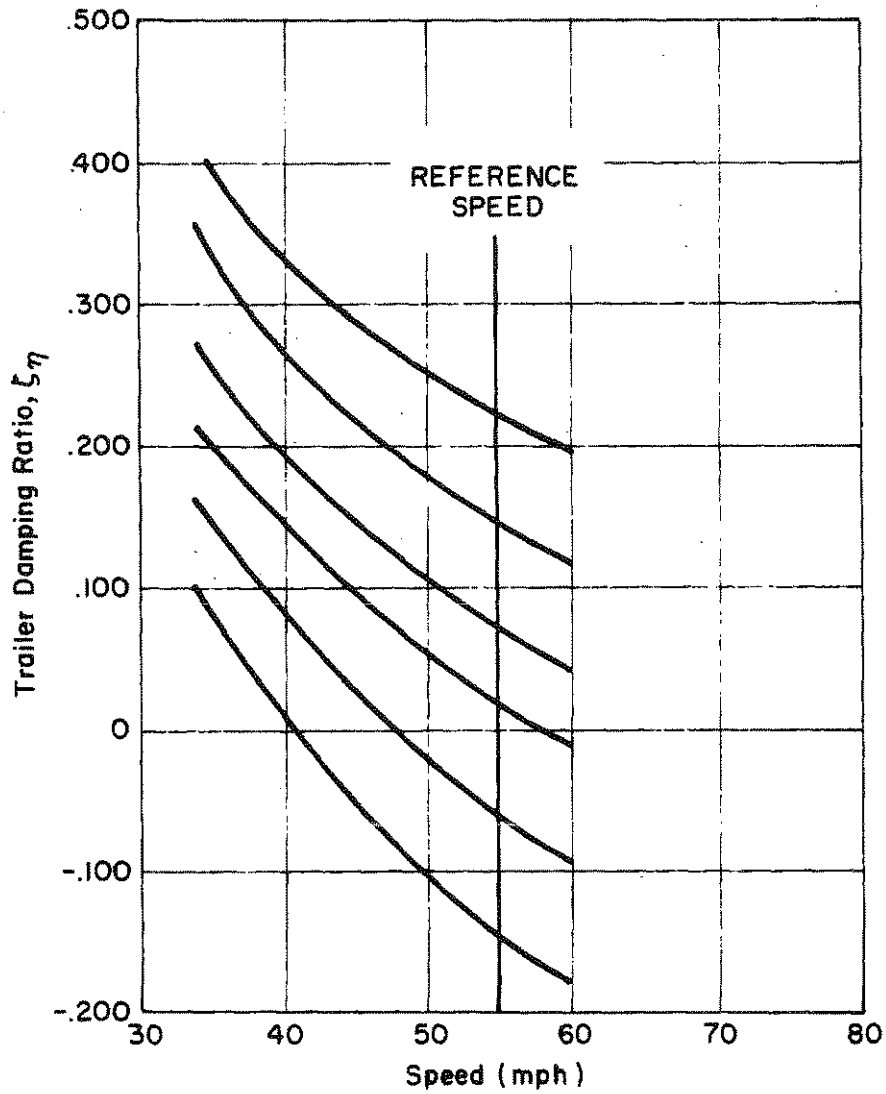
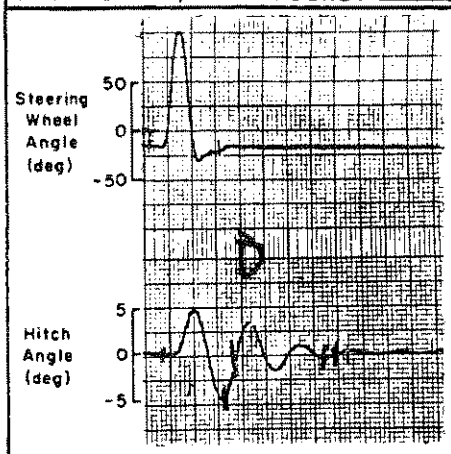


Figure E-1. Trailer Damping Speed Adjustment Curves

TABLE E-1. SUMMARY OF TRAILER DAMPING RATIO AT 55 MILES PER HOUR

Trailer (Weight)	Tow Car*	Percent Hitch Load (Percent Load Leveling in Parenthesis)								
		0	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0
Utility 1500	I	0.090		0.135		0.195				0.305
	C	0.050		0.150		0.250				
	SC	0.030	0.090	0.120	0.165	0.190				
Camper 1600	I	0.105		0.120		0.190		0.265		0.280
	C	0.020		0.080		0.160				
	SC	0.00		0.040		0.135				
18 ft Travel 3880	I			-0.055		0.095 (25)				0.285 (-25) 0.410 (+25)
	C			-0.04 (20)		+0.19 (35)		0.37 (23)		
	SC			-0.115 (10)	+0.01 (7)	+0.17 (36)		+0.37 (31)		
19 ft Travel 4000	I			-0.10		0.03		0.229 (25)		
	C			-0.15 (0)		0.05 (10)				
	SC			-0.115		+0.075 (0)				
22 ft Travel 4000	I	-0.055		0.05		0.105 0.150 (0) 0.195 (25)				0.510 (25)
	C			-0.065	+0.05	0.135 (-29)	0.47 (-6)	0.51 (-9) 0.66 (17)	0.71 (4)	
	SC			-0.05	-0.02	+0.18 (0)				
27 ft Travel 6000	I			-0.08		0.22 (25)		0.35 (25)		
	C			-0.10 (13)		+0.41 (15)				
20 ft Boat Trailer 3000	I	0.085		0.130		NA		0.260 0.504 (25)		
	C	-0.02		+0.03		0.10		0.413 (35)		
	SC	-0.03	+0.035	+0.05 +0.09 (0)	0.19 (0)	0.39 (32)		0.56 (21)		
Horse 5800	I					0.113		0.275		
Horse 4000	C			-0.08		+0.23				
	SC			-0.13		+0.165				

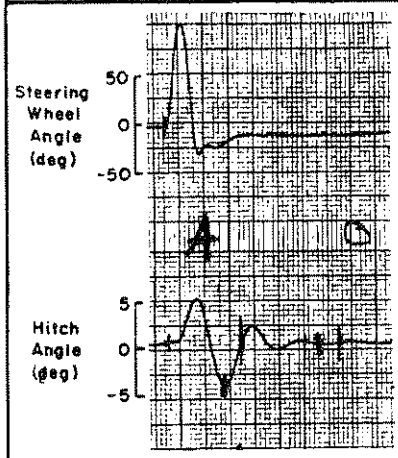
C-V: I - UTILITY
Hitch Load: 10%
Load Level/Air Shocks: NO / NO



Run No. 85 Speed 53.44 mph
ζ_η; ω_η .166 ; 6.16

AVG. OF 4 RESP = [ζ_η = .205] @ 53.44 MPH

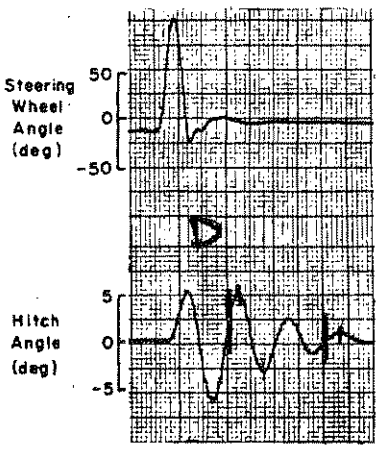
C-V: I - UTILITY
Hitch Load: 20%
Load Level/Air Shocks: NO / YES



Run No. 109 Speed 52.37 mph
ζ_η; ω_η .293 ; 6.54

[.320] @ 52.37

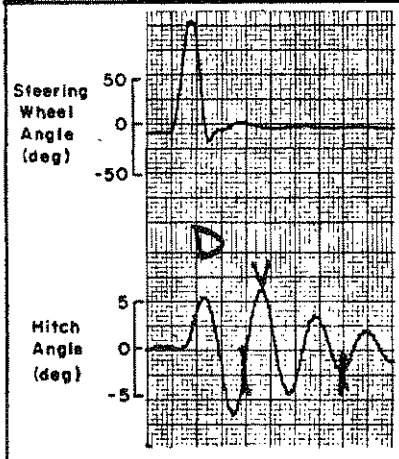
C-V: I - UTILITY
Hitch Load: 5%
Load Level/Air Shocks: NO / NO



Run No. 141 Speed 54.37 mph
ζ_η; ω_η .136 ; 6.23

[.136] @ 54.73

C-V: I - UTILITY
Hitch Load: 0%
Load Level/Air Shocks: NO / NO

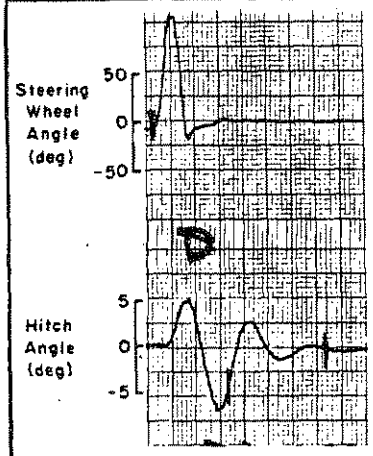


Run No. 148 Speed 52.15 mph
ζ_η; ω_η .100 ; 5.85

[.109] @ 52.5

Figure E-2. Trailer Swing Time Histories for Intermediate Tow Car

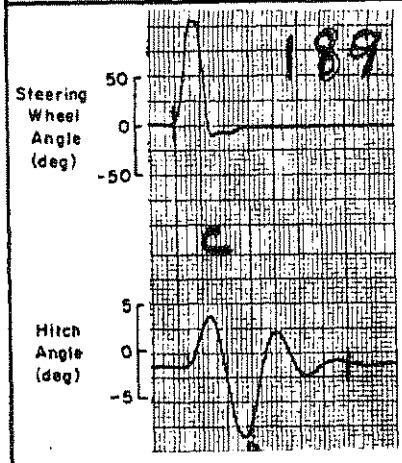
C-V: I - CAMPER
Hitch Load: 20 %
Load Level/Air Shocks: NO / YES



Run No. 166 Speed 54.73 mph
ζ_n; ω_n .294 ; 5.30

[.282] @ 54.73

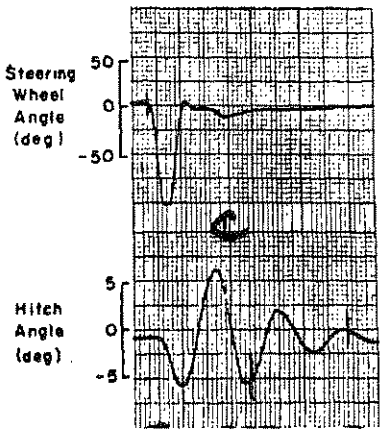
C-V: I - CAMPER
Hitch Load: 15 %
Load Level/Air Shocks: NO / YES



Run No. 189 Speed 52.37 mph
ζ_n; ω_n .289 ; 5.23

[.280] @ 52.37

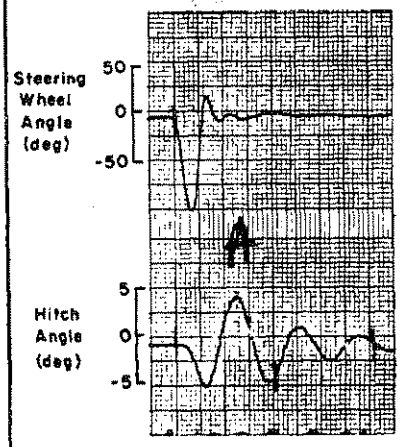
C-V: I - CAMPER
Hitch Load: 10 %
Load Level/Air Shocks: NO / YES



Run No. 217 Speed 55.80 mph
ζ_n; ω_n .173 ; 4.84

[.186] @ 55.8

C-V: I - CAMPER
Hitch Load: 5 %
Load Level/Air Shocks: NO / YES

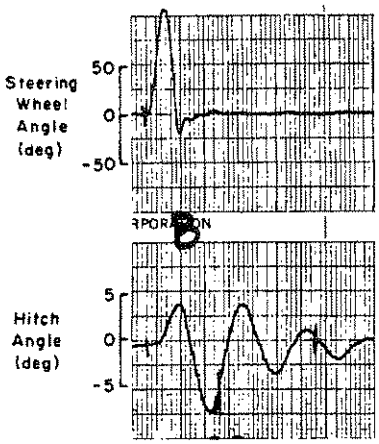


Run No. 239 Speed 52.37 mph
ζ_n; ω_n .116 ; 5.26

[.138] @ 52.73

Figure E-2 (Continued)

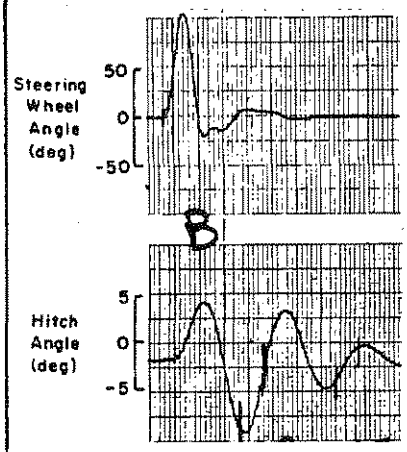
C-V: I - CAMPER
Hitch Load: 1%
Load Level/Air Shocks: No / No



Run No. 267 Speed 50.22 mph
ζ_η; ω_η .144 ; 4.78

[.149] @ 50.22

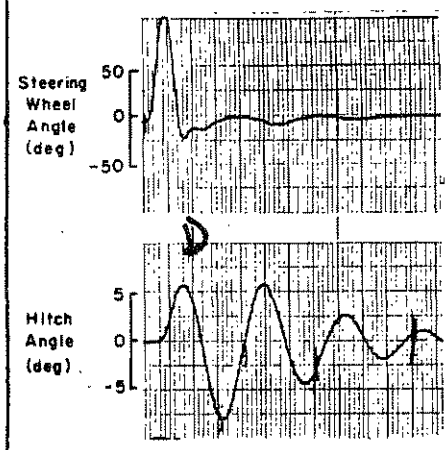
C-V: I - 22' TRAVEL
Hitch Load: 10%
Load Level/Air Shocks: 0%/ No



Run No. 295-A Speed 51.51 mph
ζ_η; ω_η .157 ; 3.86

[.170] @ 51.94

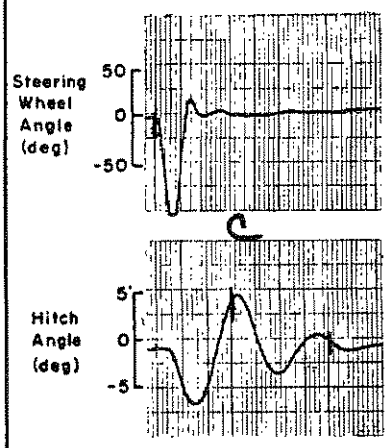
C-V: I - 22' TRAVEL
Hitch Load: 10%
Load Level/Air Shocks: No / YES



Run No. 324-B Speed 51.08 mph
ζ_η; ω_η .135 ; 4.12

[.135] @ 51.83

C-V: I - 22' TRAVEL
Hitch Load: 10%
Load Level/Air Shocks: 25%/ No

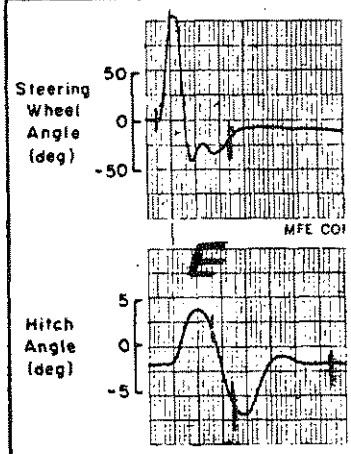


Run No. 345-B Speed 49.36 mph
ζ_η; ω_η .216 ; 4.06

[.227] @ 50.82

Figure E-2 (Continued)

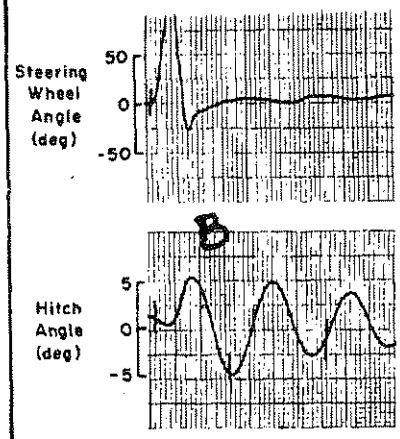
C-V: I - 22' TRAVEL
Hitch Load: 20%
Load Level/Air Shocks: 25%/ No



Run No. 357-B Speed 52.37 mph
ζ_η; ω_η .522 ; 4.36

[.526] @ 52.37

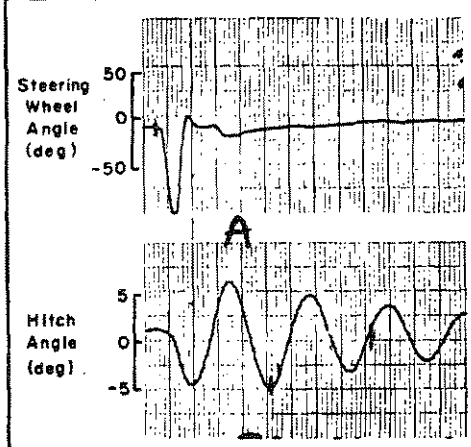
C-V: I - 22' TRAVEL
Hitch Load: 0%
Load Level/Air Shocks: No/ No



Run No. 374-A Speed 39.28 mph
ζ_η; ω_η .066 ; 3.97

[.088] @ 40.24

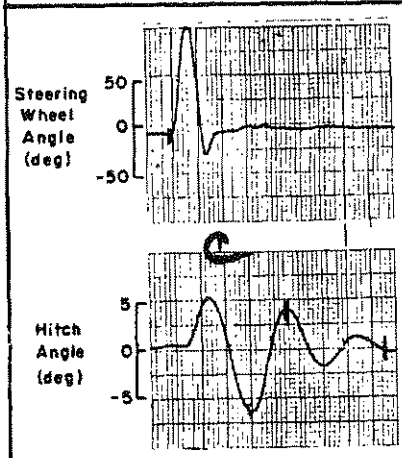
C-V: I - 22' TRAVEL
Hitch Load: 5%
Load Level/Air Shocks: No / YES



Run No. 377A Speed 53.23 mph
ζ_η; ω_η .060 ; 4.05

[.061] @ 52.80

C-V: I - 18' TRAVEL [3000 LB]
Hitch Load: 13%
Load Level/Air Shocks: 25% / No

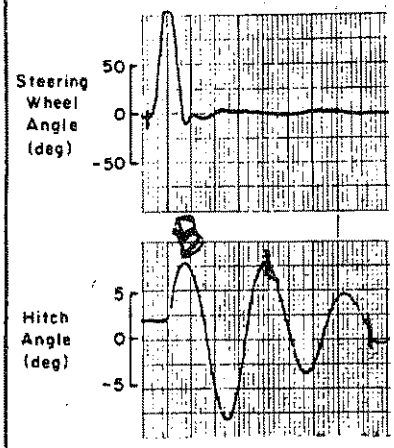


Run No. 413 Speed 55.16 mph
ζ_η; ω_η .205 ; 4.69

[.206] @ 55.16

Figure E-2 (Continued)

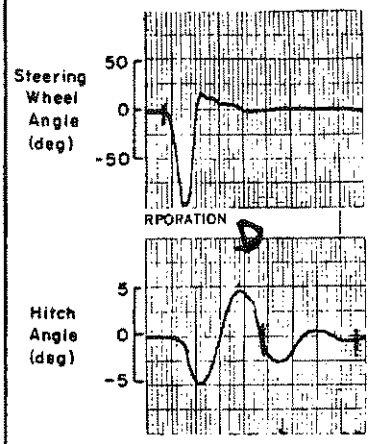
C-V: I - 18' TRAVEL [3000 LB]
Hitch Load: 13%
Load Level/Air Shocks: NO / YES



Run No. 433 Speed 52.37 mph
ζ_η; ω_η .107 ; 4.19

[.131] @ 52.37

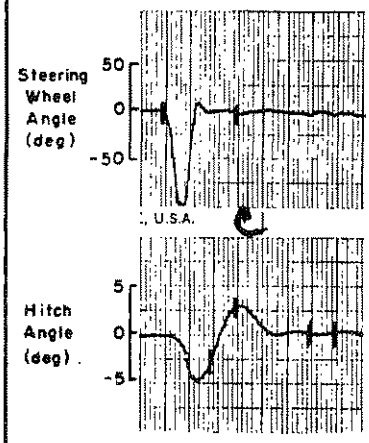
C-V: I - 18' TRAVEL
Hitch Load: 20%
Load Level/Air Shocks: -25% / YES



Run No. 463 Speed 53.66 mph
ζ_η; ω_η .318 ; 4.46

[.296] @ 53.66

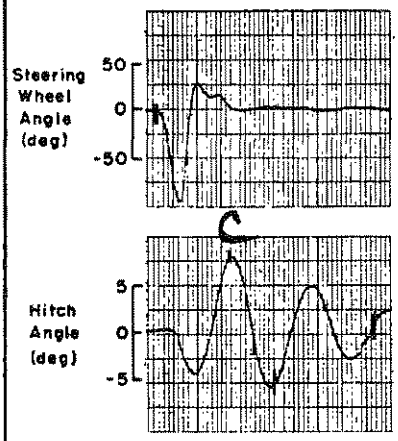
C-V: I - 18' TRAVEL
Hitch Load: 20%
Load Level/Air Shocks: 25% / NO



Run No. 500 Speed 53.23 mph
ζ_η; ω_η .584 ; 5.15

[.414] @ 53.23

C-V: I - 18' TRAVEL
Hitch Load: 10%
Load Level/Air Shocks: 25% / NO

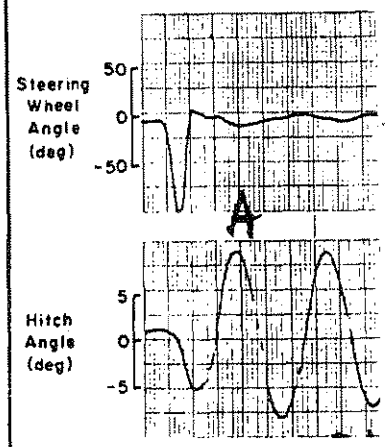


Run No. 533-B Speed 55.80 mph
ζ_η; ω_η .105 ; 3.98

[.105] @ 53.32

Figure E-2 (Continued)

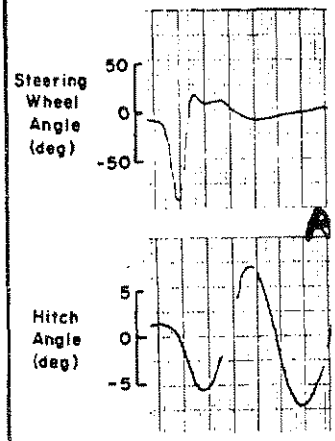
C-V: I - 18' TRAVEL
Hitch Load: 5%
Load Level/Air Shocks: NO / NO



Run No. 569 A Speed 45.29 mph
ζ_η; ω_η .047 ; 4.18

[0.0] @ 48.72

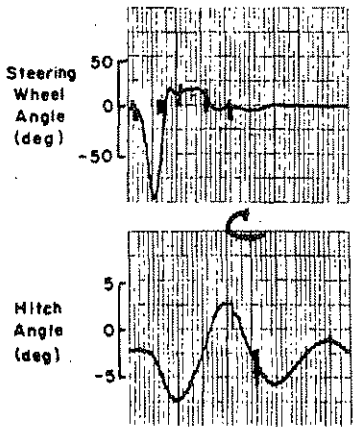
C-V: I - 27' TRAVEL
Hitch Load: 5%
Load Level/Air Shocks: NO / YES



Run No. 571 Speed 43.78 mph
ζ_η; ω_η .038 ; 3.12

[0.0] @ 45.72

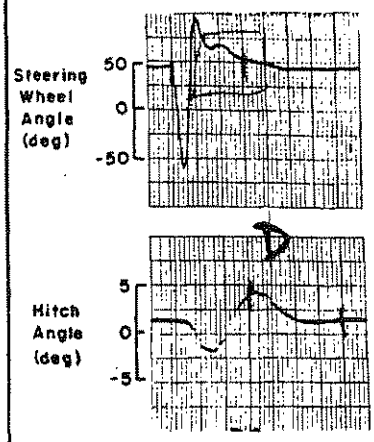
C-V: I - 27' TRAVEL
Hitch Load: 10%
Load Level/Air Shocks: 25% / NO



Run No. 513 Speed 52.15 mph
ζ_η; ω_η .189 , 3.22

[.239] @ 52.15

C-V: I - 27' TRAVEL
Hitch Load: 15%
Load Level/Air Shocks: 25% / NO

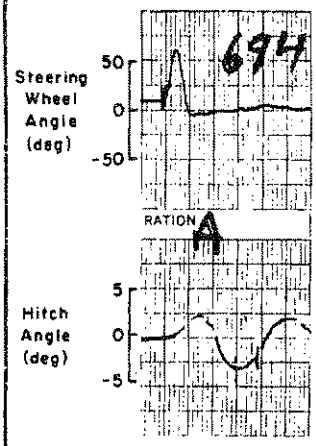


Run No. 659 Speed 48.51 mph
ζ_η; ω_η .524 ; 3.00

[.366] @ 51.0

Figure E-2 (Continued)

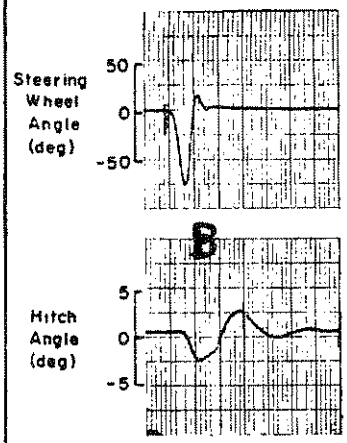
C-V: I - 27' TRAVEL
Hitch Load: 5%
Load Level/Air Shocks: NO / YES



Run No. 694 Speed 43.36 mph
ζ_η; ω_η .112 ; 3.28

[DYN. SWAY DAMPER]

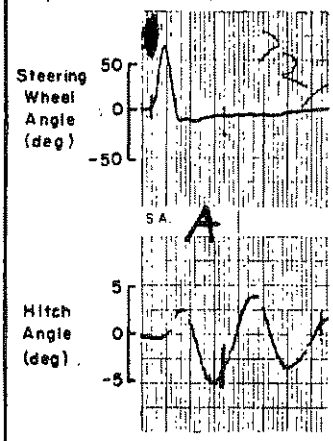
C-V: I - HORSE
Hitch Load: 15%
Load Level/Air Shocks: NO / YES



Run No. 700 Speed 49.79 mph
ζ_η; ω_η .350 ; 4.87

[.282] @ 53.23

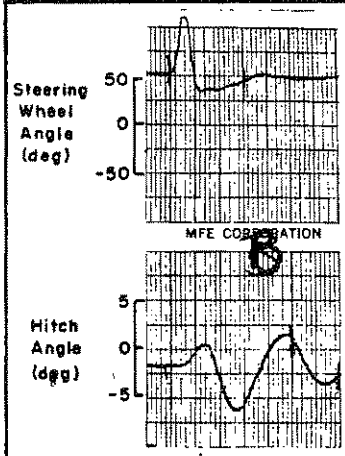
C-V: I. HORSE
Hitch Load: 10%
Load Level/Air Shocks: NO / YES



Run No. 720 Speed 55.37 mph
ζ_η; ω_η .146 ; 4.35

[.113] @ 54.9

C-V: I - 19' TRAVEL
Hitch Load: 15%
Load Level/Air Shocks: 25% / NO

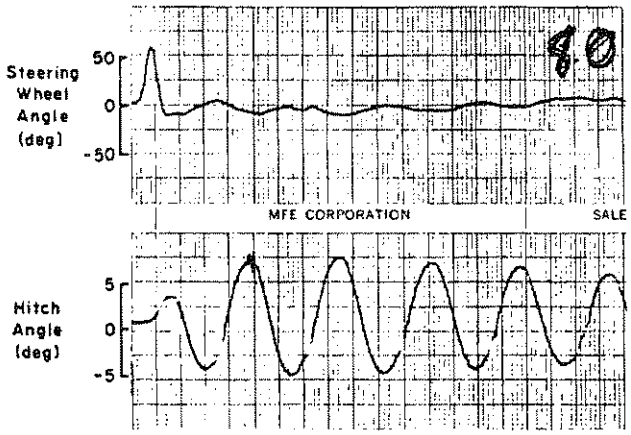


Run No. 770 Speed 56.37 mph
ζ_η; ω_η .221 ; 3.84

[.228] @ 55.17

Figure E-2 (Continued)

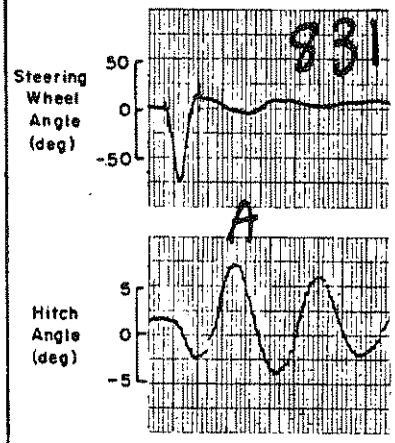
C-V: I - 19' TRAVEL
Hitch Load: 5%
Load Level/Air Shocks: NO / YES



Run No. 802 Speed 51.08 mph
ζ_η; ω_η 0.0 ; 3.45

[0.0] @ 44.0 to 51.0

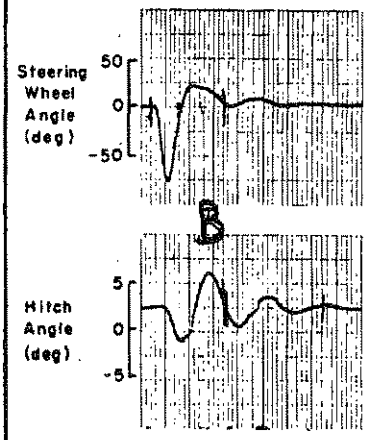
C-V: I - 19' TRAVEL
Hitch Load: 10%
Load Level/Air Shocks: NO / YES



Run No. 831 Speed 53.23 mph
ζ_η; ω_η .042 ; 3.96

[.052] @ 52.2

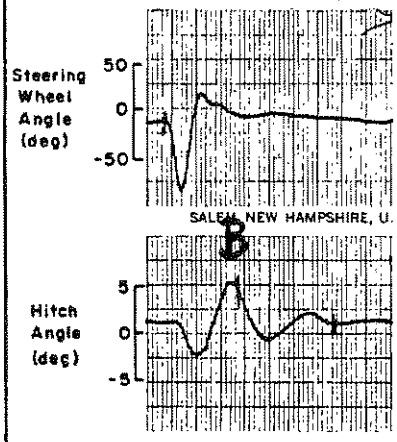
C-V: I- HORSE [2000 LB]
Hitch Load: 9%
Load Level/Air Shocks: NO / YES



Run No. 816 Speed 55.59 mph
ζ_η; ω_η .184 ; 5.72

[.188] @ 54.88

C-V: I- BOAT
Hitch Load: 13%
Load Level/Air Shocks: NO / YES

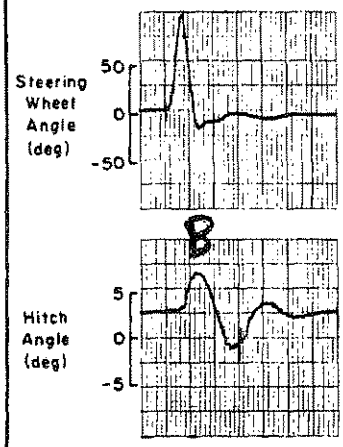


Run No. 926 Speed 57.09 mph
ζ_η; ω_η .240 ; 4.44

[.254] @ 56.6

Figure E-2 (Continued)

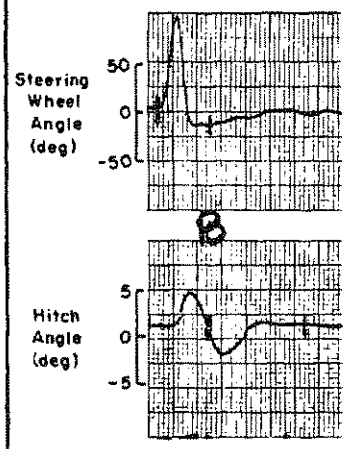
C-V: I - Boat
Hitch Load: 15%
Load Level/Air Shocks: NO / YES



Run No. 942 Speed 53.44 mph
ζ_n; ω_n .317 ; 5.39

[.268] @ 53.44

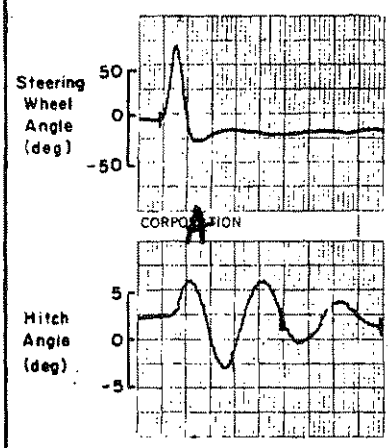
C-V: I - Boat
Hitch Load: 15%
Load Level/Air Shocks: 25% / NO



Run No. 956 Speed 55.80 mph
ζ_n; ω_n .513 ; 4.17

[.504] @ 55.07

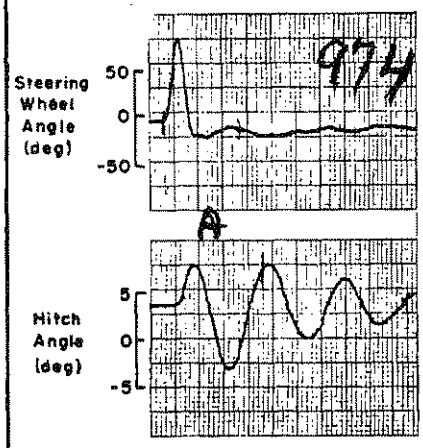
C-V: I - Boat
Hitch Load: 5%
Load Level/Air Shocks: No / YES



Run No. 972 Speed 54.73 mph
ζ_n; ω_n .156 ; 4.10

[.130] @ 54.73

C-V: I - Boat
Hitch Load: 0.5%
Load Level/Air Shocks: NO / NO

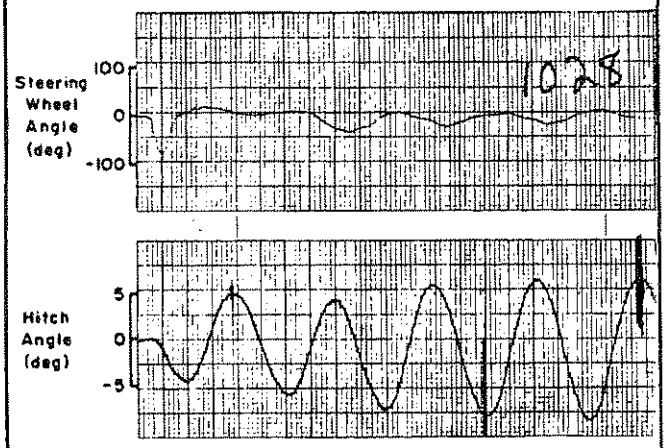


Run No. 974 Speed 56.66 mph
ζ_n; ω_n .083 ; 4.06

[.086] @ 54.6

Figure E-2 (Concluded)

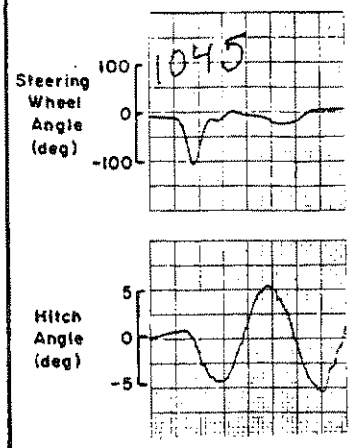
C-V: C - 22' TRAVEL
Hitch Load: 5%
Load Level/Air Shocks: NO / YES



Run No. 1028 Speed 49.0 mph
ζ_η; ω_η 0.0 ; 2.99

[0.0] @ 48.0

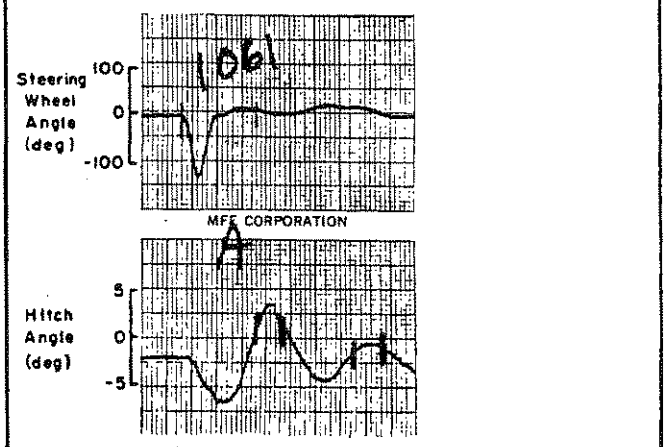
C-V: C - 22' TRAVEL
Hitch Load: 7.5%
Load Level/Air Shocks: NO / YES



Run No. 1045 Speed 51.94 mph
ζ_η; ω_η .062 ; 3.13

[.062] @ 51.94

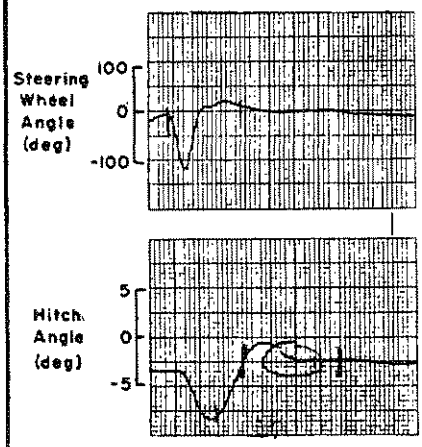
C-V: C - 22' TRAVEL
Hitch Load: 10%
Load Level/Air Shocks: -29% / YES



Run No. 1061 Speed 51.30 mph
ζ_η; ω_η .110 ; 3.46

[.150] @ 52.62

C-V: C - 22' TRAVEL
Hitch Load: 12.5%
Load Level/Air Shocks: -6% / YES

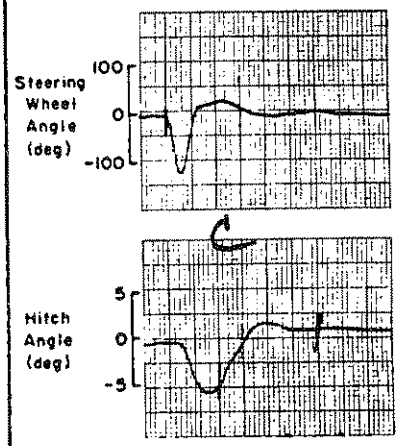


Run No. 1076 Speed 51.30 mph
ζ_η; ω_η .518 ; 3.65

[.485] @ 51.90

Figure E-3. Trailer Swing Time Histories for Compact Tow Car

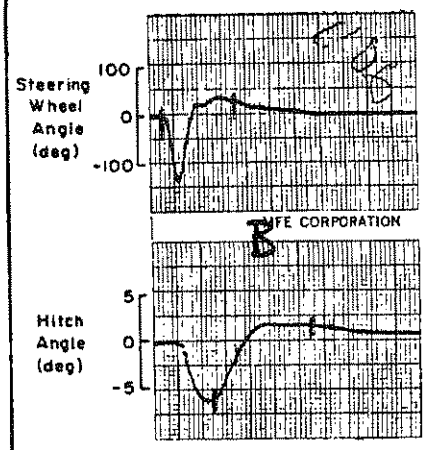
C-V: C - 22' TRAVEL
Hitch Load: 15%
Load Level/Air Shocks: -7% / YES



Run No. 1090 Speed 53.44 mph
ζ_η; ω_η .518 ; 4.37

[.518] @ 53.44

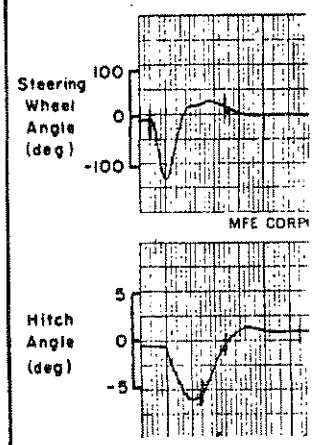
C-V: C - 22' TRAVEL
Hitch Load: 17.5%
Load Level/Air Shocks: 4% / YES



Run No. 1105 Speed 50.01 mph
ζ_η; ω_η .724 ; 3.61

[.728] @ 50.65

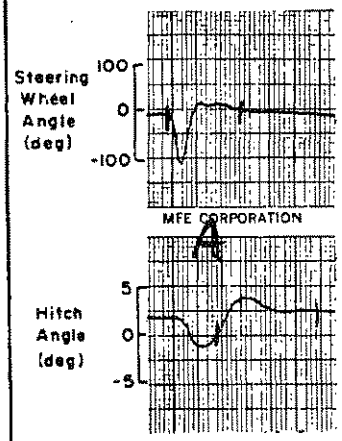
C-V: C - 22' TRAVEL
Hitch Load: 15%
Load Level/Air Shocks: 17% / NO



Run No. 1118 Speed 52.58 mph
ζ_η; ω_η .625 ; 4.29

[.673] @ 51.0

C-V: C - Boat
Hitch Load: 15%
Load Level/Air Shocks: 35% / NO

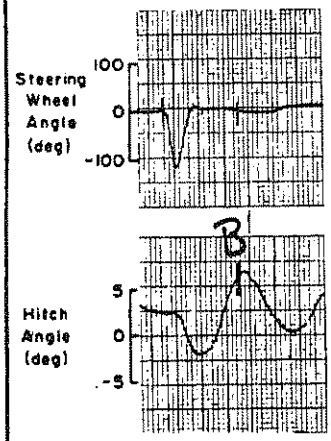


Run No. 1183 Speed 53.23 mph
ζ_η; ω_η .339 ; 3.53

[.425] @ 53.3

Figure E-3 (Continued)

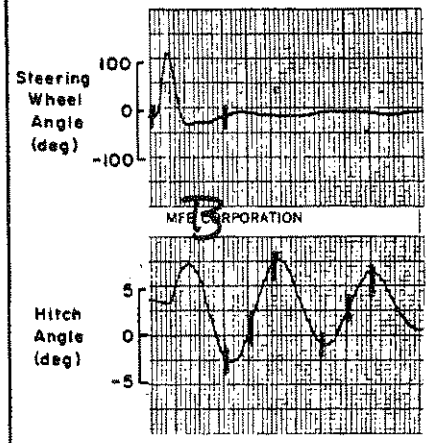
C-V: C - Boat
Hitch Load: 10%
Load Level/Air Shocks: NO / YES



Run No. 1197 Speed 53.44 mph
ζ_n; ω_n .097 ; 3.54

[.111] @ 53.87

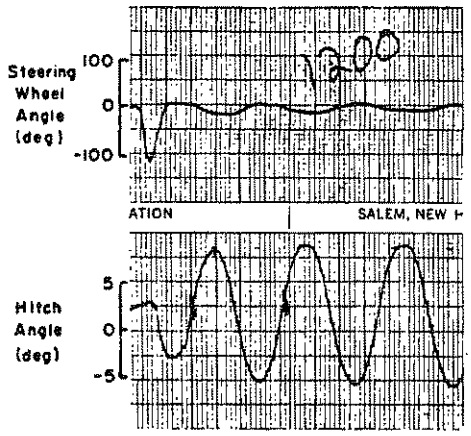
C-V: C - Boat
Hitch Load: 5%
Load Level/Air Shocks: NO / YES



Run No. 1199 Speed 53.66 mph
ζ_n; ω_n .046 ; 3.37

[.044] @ 52.63

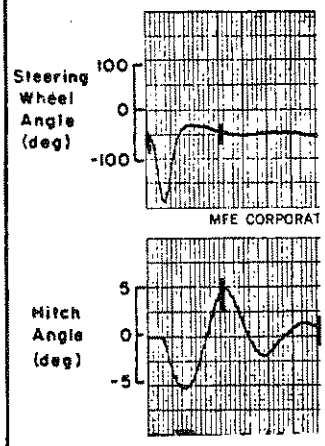
C-V: C - Boat
Hitch Load: 0%
Load Level/Air Shocks: NO / NO



Run No. 1200 Speed 51.00 mph
ζ_n; ω_n 0.0 ; 3.20

[0.0] @ 51.0

C-V: C - Horse
Hitch Load: 10%
Load Level/Air Shocks: NO / YES

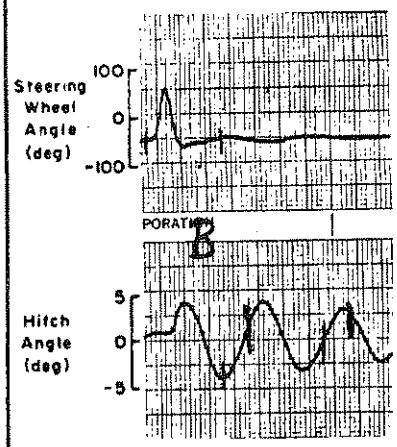


Run No. 1274 Speed 54.52 mph
ζ_n; ω_n .231 ; 4.13

[.230] @ 54.4

Figure E-3 (Continued)

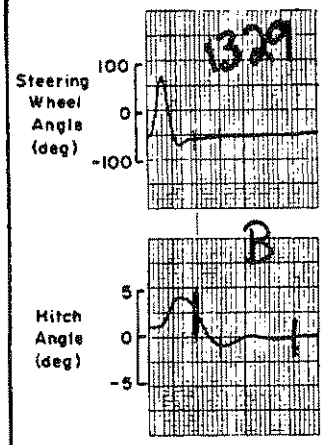
C-V: C - HORSES
Hitch Load: 5%
Load Level/Air Shocks: NO / YES



Run No. 1292 Speed 45.92 mph
ζ_η; ω_η .036 ; 3.97

[0.0] @ 46.0

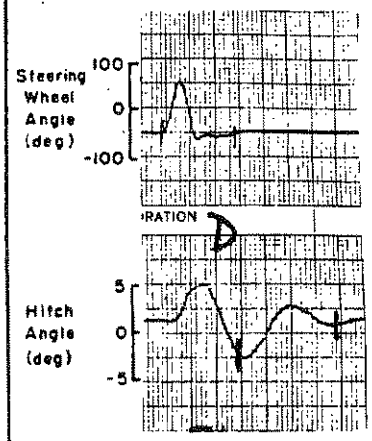
C-V: C - 18' TRAVEL
Hitch Load: 15%
Load Level/Air Shocks: 23% / NO



Run No. 1329 Speed 50.44 mph
ζ_η; ω_η .408 ; 5.35

[.392] @ 50.12

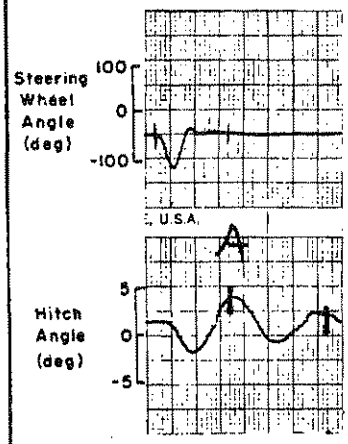
C-V: C - 18' TRAVEL
Hitch Load: 10%
Load Level/Air Shocks: 35% / NO



Run No. 1350 Speed 50.65 mph
ζ_η; ω_η .304 ; 3.74

[.221] @ 50.44

C-V: C - 18' TRAVEL
Hitch Load: 5%
Load Level/Air Shocks: 20% / NO

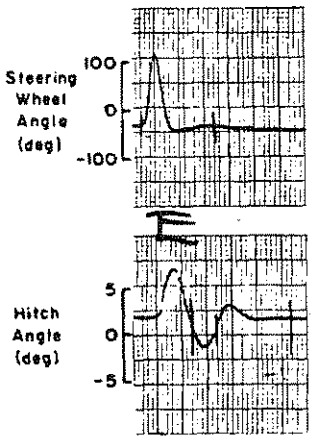


Run No. 1351-A Speed 45.72 mph
ζ_η; ω_η .138 , 3.81

[0.0] @ 50.0

Figure E-3 (Continued)

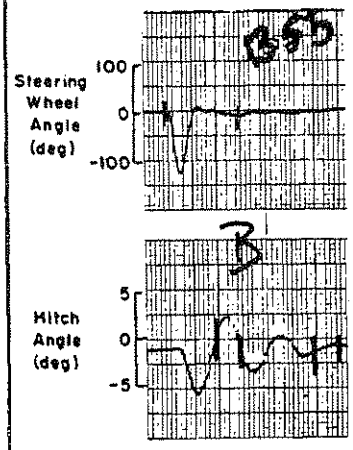
C-V: C Utility
Hitch Load: 10%
Load Level/Air Shocks: No / YES



Run No. 1353 Speed 54.95 mph
ζ_n; ω_n .256 ; 5.60

[.255] @ 54.73

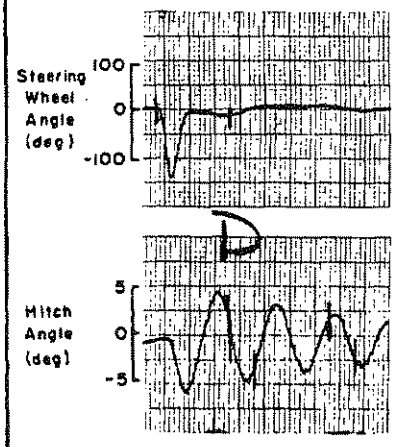
C-V: C- Utility
Hitch Load: 5%
Load Level/Air Shocks: No / YES



Run No. 1355 Speed 51.73 mph
ζ_n; ω_n .159 ; 5.82

[.168] @ 52.14

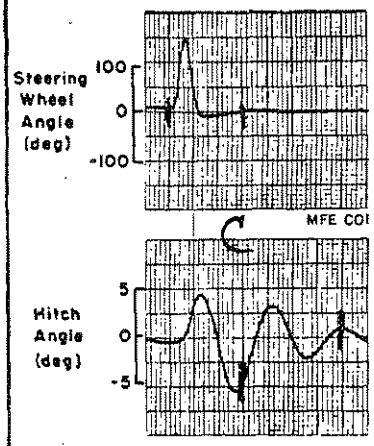
C-V: C- Utility
Hitch Load: 0%
Load Level/Air Shocks: No / NO



Run No. 1356 Speed 53.01 mph
ζ_n; ω_n .046 ; 5.54

[.063] @ 52.0

C-V: C- Camper
Hitch Load: 10%
Load Level/Air Shocks: No / YES

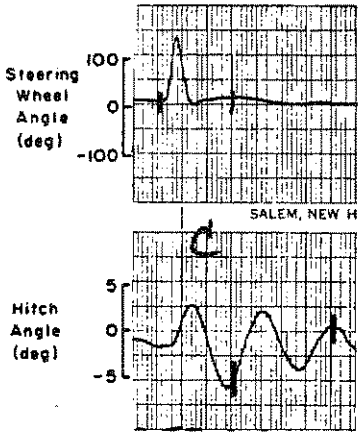


Run No. 1357 Speed 54.00 mph
ζ_n; ω_n .166 ; 4.41

[.170] @ 54.0

Figure E-3 (Continued)

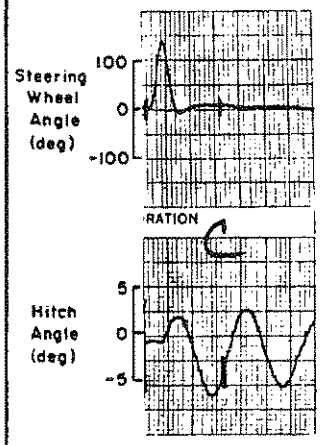
C-V: C - Camper
Hitch Load: 5%
Load Level/Air Shocks: No / YES



Run No. 1358 Speed 51.51 mph
ζ_η; ω_η .090 ; 4.52

[.095] @ 51.9

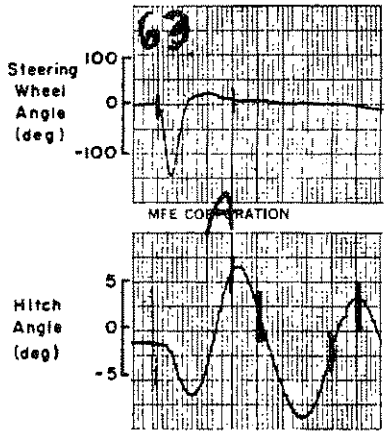
C-V: C - Camper
Hitch Load: 0%
Load Level/Air Shocks: NO/NO



Run No. 1359 Speed 51.51 mph
ζ_η; ω_η .050 ; 4.38

[.051] @ 51.3

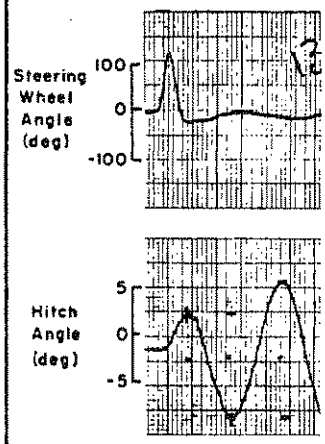
C-V: C - 19' TRAVEL
Hitch Load: 10%
Load Level/Air Shocks: 10% / NO



Run No. 1363 Speed 50.65 mph
ζ_η; ω_η .019 ; 2.79

[.092] @ 49.7

C-V: C - 19' TRAVEL
Hitch Load: 5%
Load Level/Air Shocks: 0% / NO

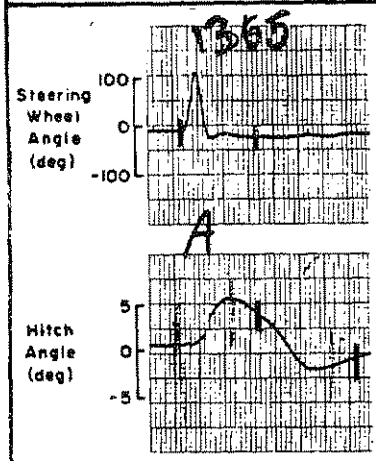


Run No. 1364 Speed 49.0 mph
ζ_η; ω_η -.092 ; 3.06

[0.0] @ 41.0

Figure E-3 (Continued)

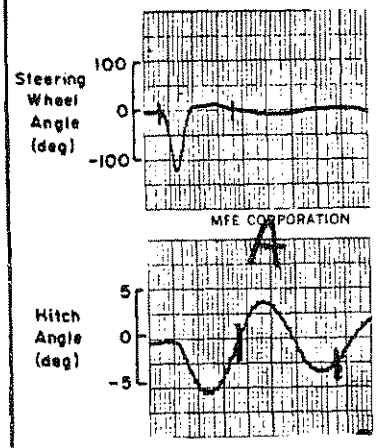
C-V: C - 27' Travel
Hitch Load: 10%
Load Level/Air Shocks: 15% / No



Run No. 1365 Speed 47.96 mph
ζ_η; ω_η .354 ; 2.93

[.446] @ 48.0

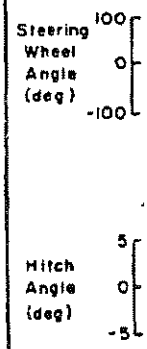
C-V: C-27' Travel
Hitch Load: 5%
Load Level/Air Shocks: 13% / No



Run No. 1378 Speed 37.99 mph
ζ_η; ω_η .046 ; 2.74

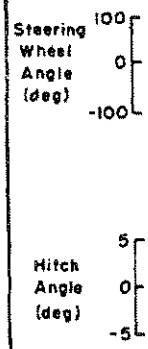
[.042] @ 40.74

C-V:
Hitch Load:
Load Level/Air Shocks:



Run No. _____ Speed _____ mph
ζ_η; ω_η _____

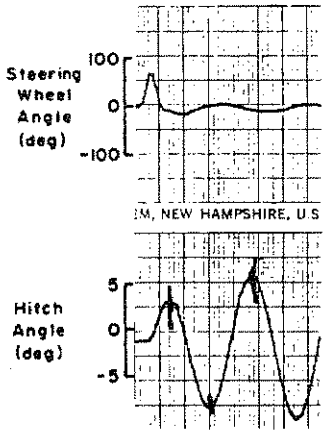
C-V:
Hitch Load:
Load Level/Air Shocks:



Run No. _____ Speed _____ mph
ζ_η; ω_η _____

Figure E-3 (Concluded)

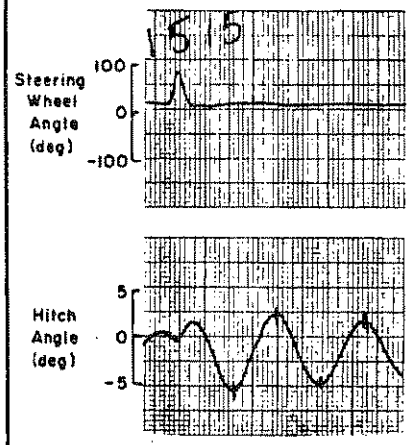
C-V: SC - 18' TRAVEL (3420 LB.)
Hitch Load: 5%
Load Level/Air Shocks: No / YES



Run No. 1502 Speed 44.0 mph
ζ_n; ω_n -.02; 3.37

[0.0] @ 42.0

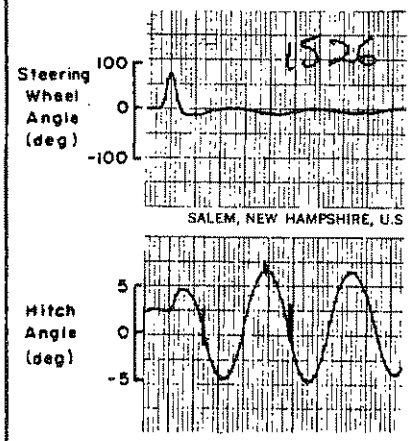
C-V: SC - 18' TRAVEL (3420 LB.)
Hitch Load: 7½ %
Load Level/Air Shocks: No / YES



Run No. 1515 Speed 51.0 mph
ζ_n; ω_n 0.0 ; 3.59

[0.0] @ 51.0

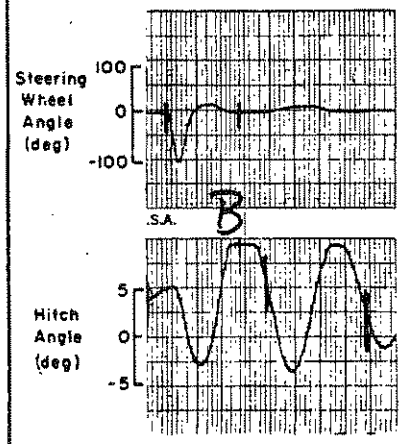
C-V: SC - Boat
Hitch Load: 0%
Load Level/Air Shocks: No / No



Run No. 1526 Speed 51.0 mph
ζ_n; ω_n 0.0 ; 3.65

[0.0] @ 51.0

C-V: SC - Boat
Hitch Load: 3%
Load Level/Air Shocks: No / YES

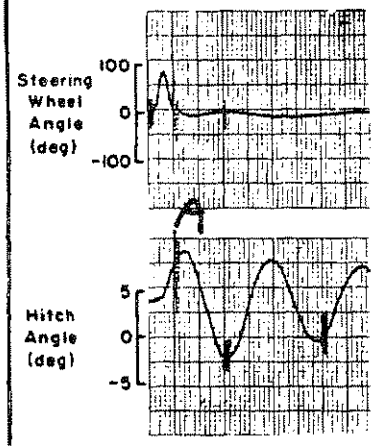


Run No. 1538 Speed 51.94 mph
ζ_n; ω_n .064 ; 3.48

[.058] @ 51.4

Figure E-4. Trailer Swing Time Histories for Subcompact Tow Car

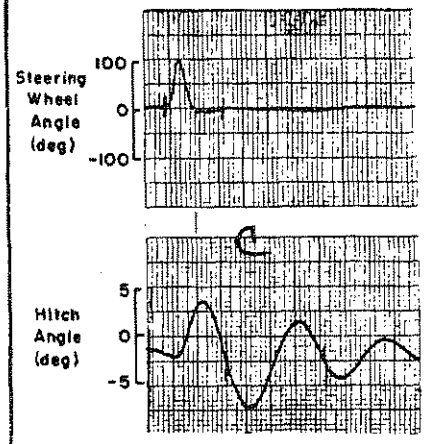
C-V: SC - Boat
Hitch Load: 5%
Load Level/Air Shocks: No / YES



Run No. 1541 Speed 54.30 mph
ζ_n; ω_n .060 ; 3.54

[.053] @ 53.36

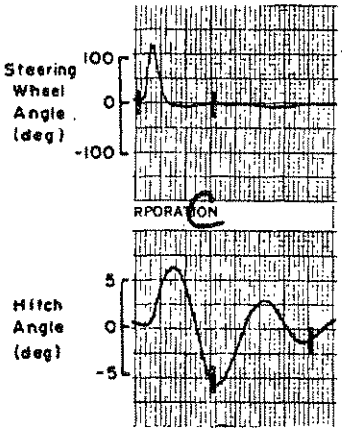
C-V: SC - Boat
Hitch Load: 5%
Load Level/Air Shocks: 0% / No



Run No. 1553 Speed 52.32 mph
ζ_n; ω_n .094 ; 3.33

[.105] @ 51.91

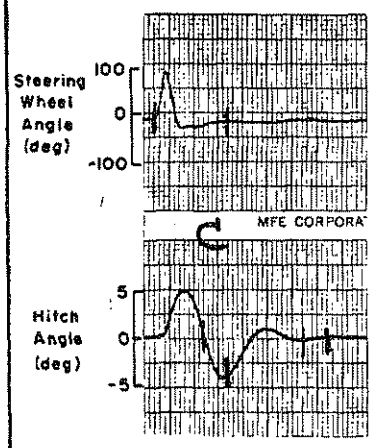
C-V: SC - Boat
Hitch Load: 7.5%
Load Level/Air Shocks: 0% / No



Run No. 1564 Speed 51.23 mph
ζ_n; ω_n .222 ; 3.57

[.203] @ 52.2

C-V: SC - Boat
Hitch Load: 10%
Load Level/Air Shocks: 32% / No

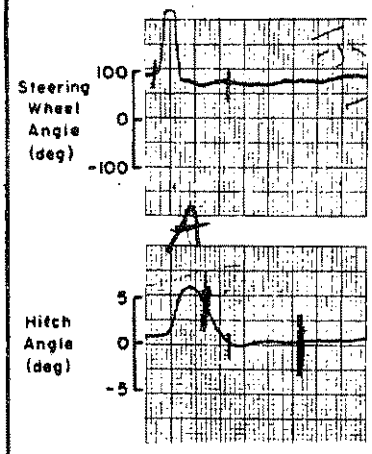


Run No. 1565 Speed 50.44 mph
ζ_n; ω_n .435 ; 4.79

[.402] @ 51.35

Figure E- (Continued)

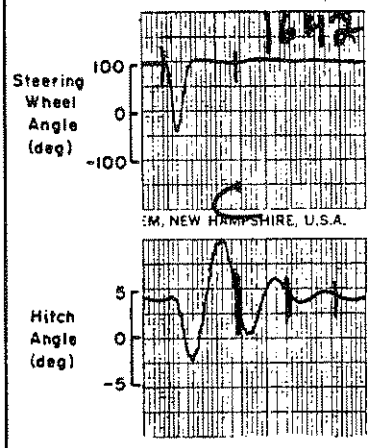
C-V: SC - Boat
Hitch Load: 15%
Load Level/Air Shocks: 21 % / No



Run No. 1569-A Speed 53.44 mph
ζ_η; ω_η .569 ; 5.30

[.569] @ 52.9

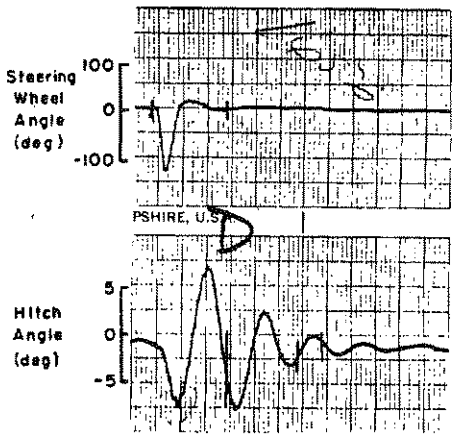
C-V: SC- Utility
Hitch Load: 10%
Load Level/Air Shocks: No / Yes



Run No. 1642 Speed 50.22 mph
ζ_η; ω_η .178 ; 6.08

[.208] @ 51.96

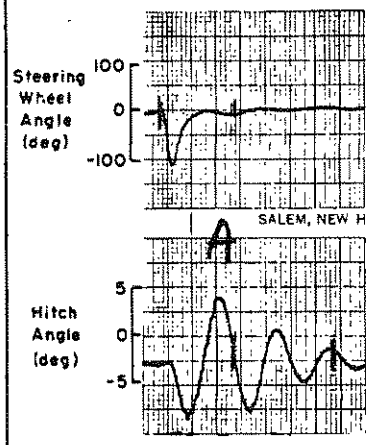
C-V: Sc- Utility
Hitch Load: 7½%
Load Level/Air Shocks: No / Yes



Run No. 1655 Speed 52.37 mph
ζ_η; ω_η .197 ; 5.66

[.187] @ 51.2

C-V: Sc- Utility
Hitch Load: 5%
Load Level/Air Shocks: No / Yes

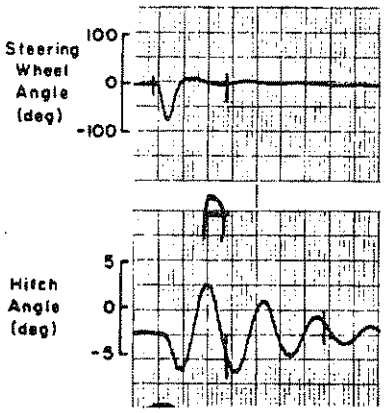


Run No. 1656 Speed 51.94 mph
ζ_η; ω_η .143 ; 5.94

[.132] @ 53.55

Figure E-4 (Continued)

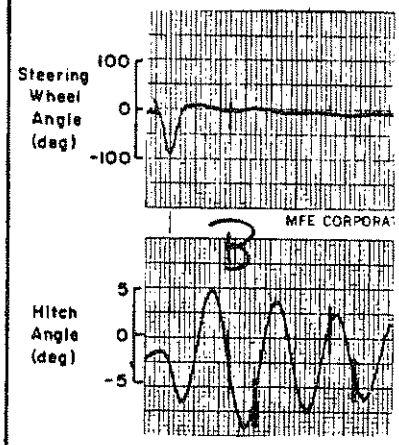
C-V: SC- Utility
Hitch Load: 2.5%
Load Level/Air Shocks: No / Yes



Run No. 1657 Speed 53.44 mph
ζ_η; ω_η .093 ; 5.77

[.096] @ 53.54

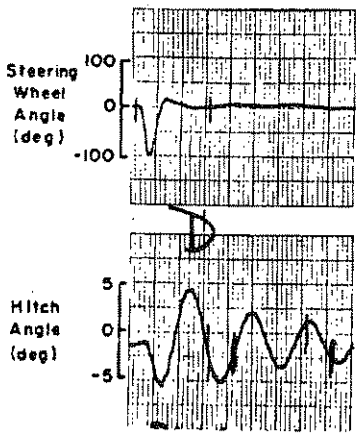
C-V: SC- Utility
Hitch Load: 0%
Load Level/Air Shocks: No / No



Run No. 1658 Speed 53.66 mph
ζ_η; ω_η .042 ; 5.35

[.046] @ 51.78

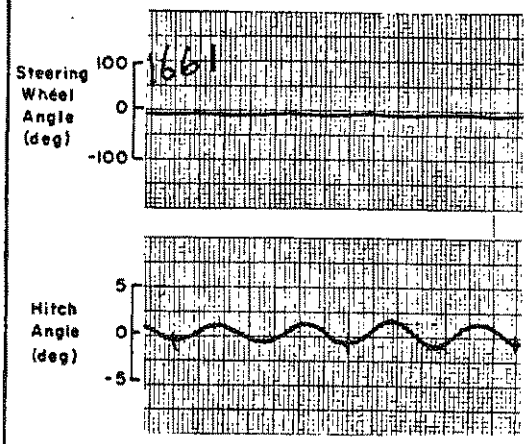
C-V: SC- Utility (LARGER I_{z_0})
Hitch Load: 5%
Load Level/Air Shocks: No / Yes



Run No. 1660 Speed 54.52 mph
ζ_η; ω_η .051 ; 5.52

[.072] @ 53.26

C-V: SC-22' TRAVEL
Hitch Load: 5%
Load Level/Air Shocks: NO / YES

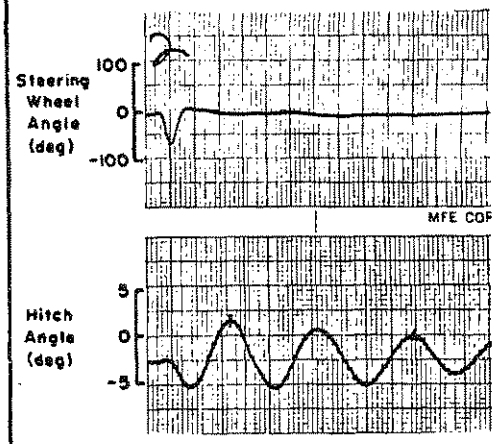


Run No. 1661 Speed 49.80 mph
ζ_η; ω_η -.035 ; 3.59

[0.0] @ 49.0

Figure E-4 (Continued)

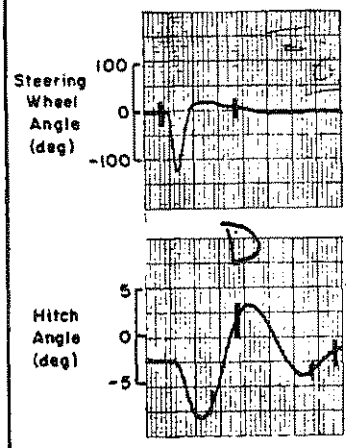
C-V: SC - 22' TRAVEL
Hitch Load: 7.5%
Load Level/Air Shocks: NO / YES



Run No. 1662 Speed 47 mph
ζ_η; ω_η .045 ; 3.39

[.045] @ 47.0

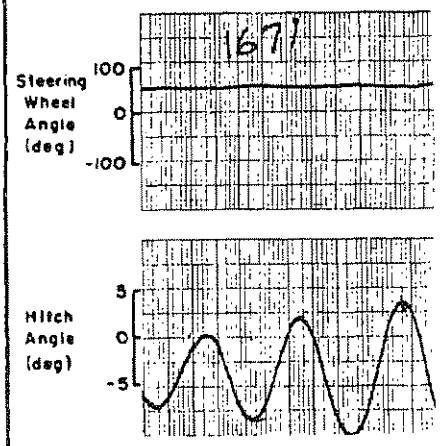
C-V: SC - 22' TRAVEL
Hitch Load: 10%
Load Level/Air Shocks: 0% / YES



Run No. 1663 Speed 43.78 mph
ζ_η; ω_η .209 ; 2.97

[.258] @ 44.64

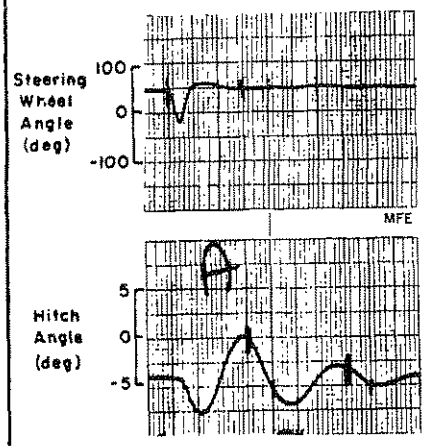
C-V: SC - 19' TRAVEL
Hitch Load: 5%
Load Level/Air Shocks: NO / YES



Run No. 1671 Speed 48.50 mph
ζ_η; ω_η -.043 ; 3.30

[0.0] @ 44.0

C-V: SC - 19' TRAVEL
Hitch Load: 10%
Load Level/Air Shocks: 0% / YES

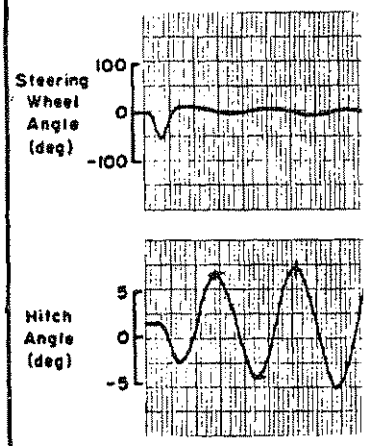


Run No. 1672 Speed 48.72 mph
ζ_η; ω_η .167 , 3.40

[.115] @ 48.88

Figure E-4 (Continued)

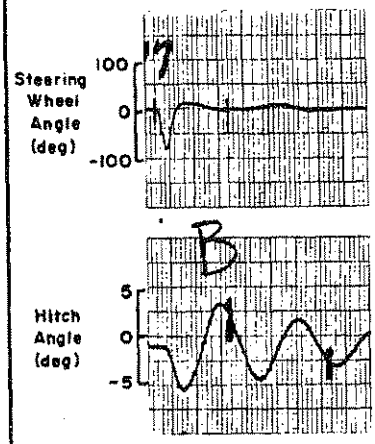
C-V: SC- HORSE
Hitch Load: 5%
Load Level/Air Shocks: No / YES



Run No. 1675 Speed 47.60 mph
ζ_η; ω_η -.034 ; 3.70

[0.0] @ 43.0

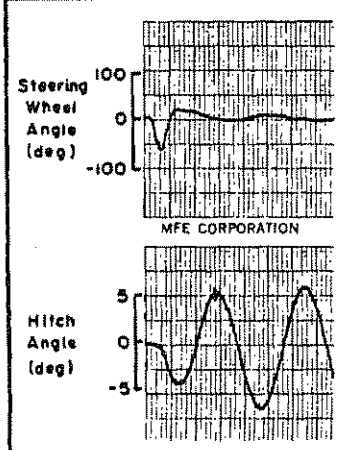
C-V: SC - HORSE
Hitch Load: 10%
Load Level/Air Shocks: No / YES



Run No. 1677 Speed 50.01 mph
ζ_η; ω_η .076 ; 4.12

[.190] @ 50.95

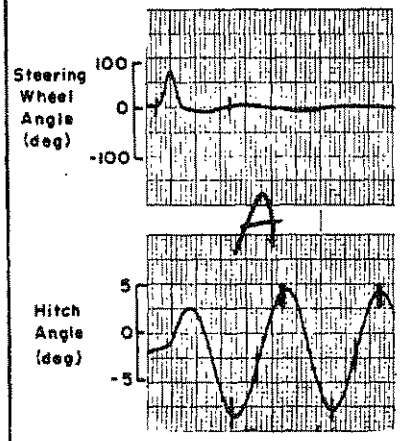
C-V: SC - 18' TRAVEL
Hitch Load: 5%
Load Level/Air Shocks: 10% / NO



Run No. 1682 Speed 46.0 mph
ζ_η; ω_η -.042 , 3.40

[0.0] @ 43.0

C-V: SC - 18' TRAVEL
Hitch Load: 7½%
Load Level/Air Shocks: 7% / NO

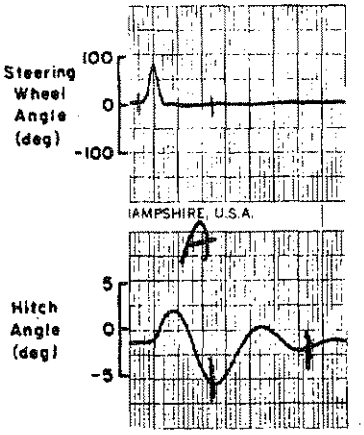


Run No. 1686 Speed 51.51 mph
ζ_η; ω_η .013 ; 3.26

[.055] @ 48.73

Figure E-4 (Continued)

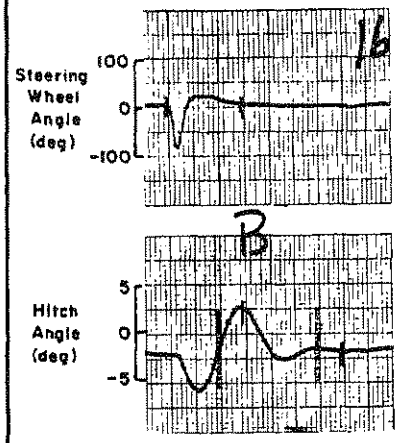
C-V: SC - 18' TRAVEL
Hitch Load: 10 %
Load Level/Air Shocks: 36 % / NO



Run No. 1688 Speed 51.73 mph
ζ_η; ω_η .279 ; 3.59

[.205] @ 49.50

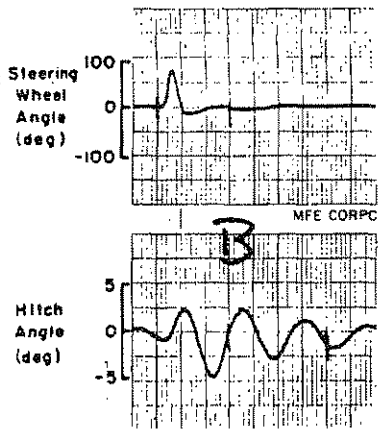
C-V: SC - 18' TRAVEL
Hitch Load: 15%
Load Level/Air Shocks: 24% / NO



Run No. 1692 Speed 50.87 mph
ζ_η; ω_η .437 ; 4.71

[.387] @ 51.45

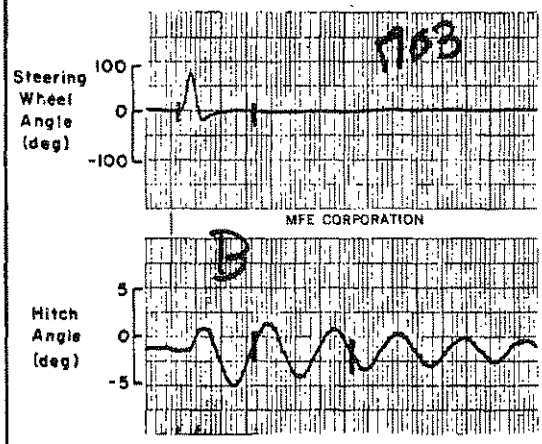
C-V: SC - Camper
Hitch Load: 5%
Load Level/Air Shocks: NO / YES



Run No. 1700 Speed 48.72 mph
ζ_η; ω_η .081 ; 5.02

[.08] @ 48.94

C-V: SC - Camper
Hitch Load: 0%
Load Level/Air Shocks: NO / NO

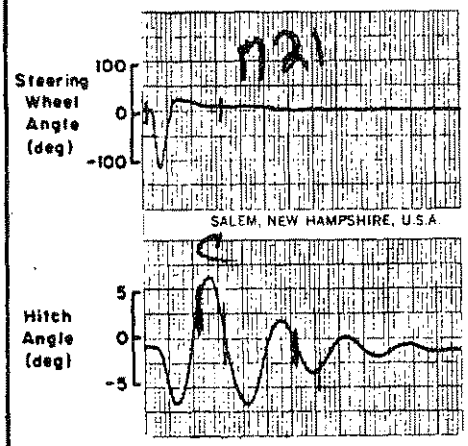


Run No. 1703 Speed 50.44 mph
ζ_η; ω_η .036 ; 4.65

[0.0] @ 55.0

Figure E-4 (Continued)

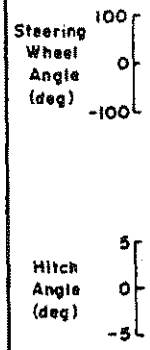
C-V: SC - Camper
Hitch Load: 10%
Load Level/Air Shocks: NO / YES



Run No. 1721 Speed 54.23 mph
ζ_η; ω_η .135 ; 4.29

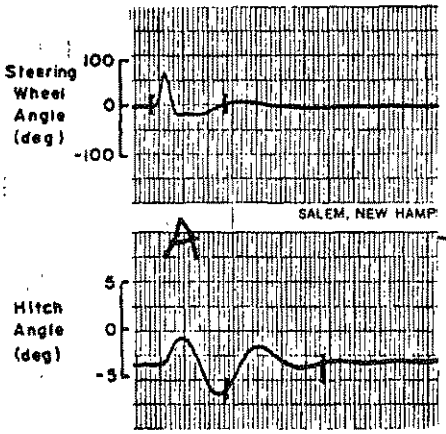
[.138] @ 54.13

C-V:
Hitch Load:
Load Level/Air Shocks:



Run No. _____ Speed _____ mph
ζ_η; ω_η _____

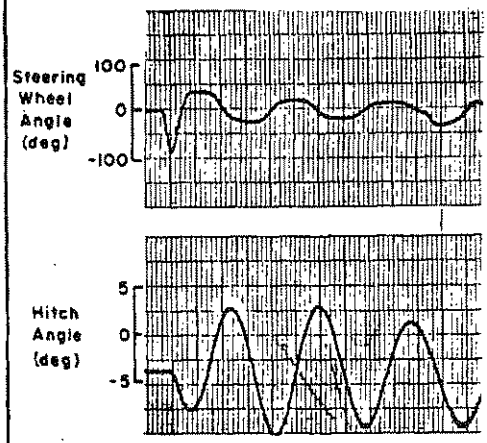
C-V: SC - 18' TRAVEL
Hitch Load: 15%
Load Level/Air Shocks: +24% L.L. / NO



PULSE THEN FIXED STEERING TEST

Run No. 1699a Speed 50 mph
ζ_η; ω_η .29

C-V: SC - 18' TRAVEL
Hitch Load: 15%
Load Level/Air Shocks: +24% LL / NO



PULSE THEN SPECIAL FREE STEERING TEST

TO BE COMPARED TO RUN 1699a

Run No. 1699b Speed 50 mph
ζ_η; ω_η ~0.0

Figure E-4 (Concluded)

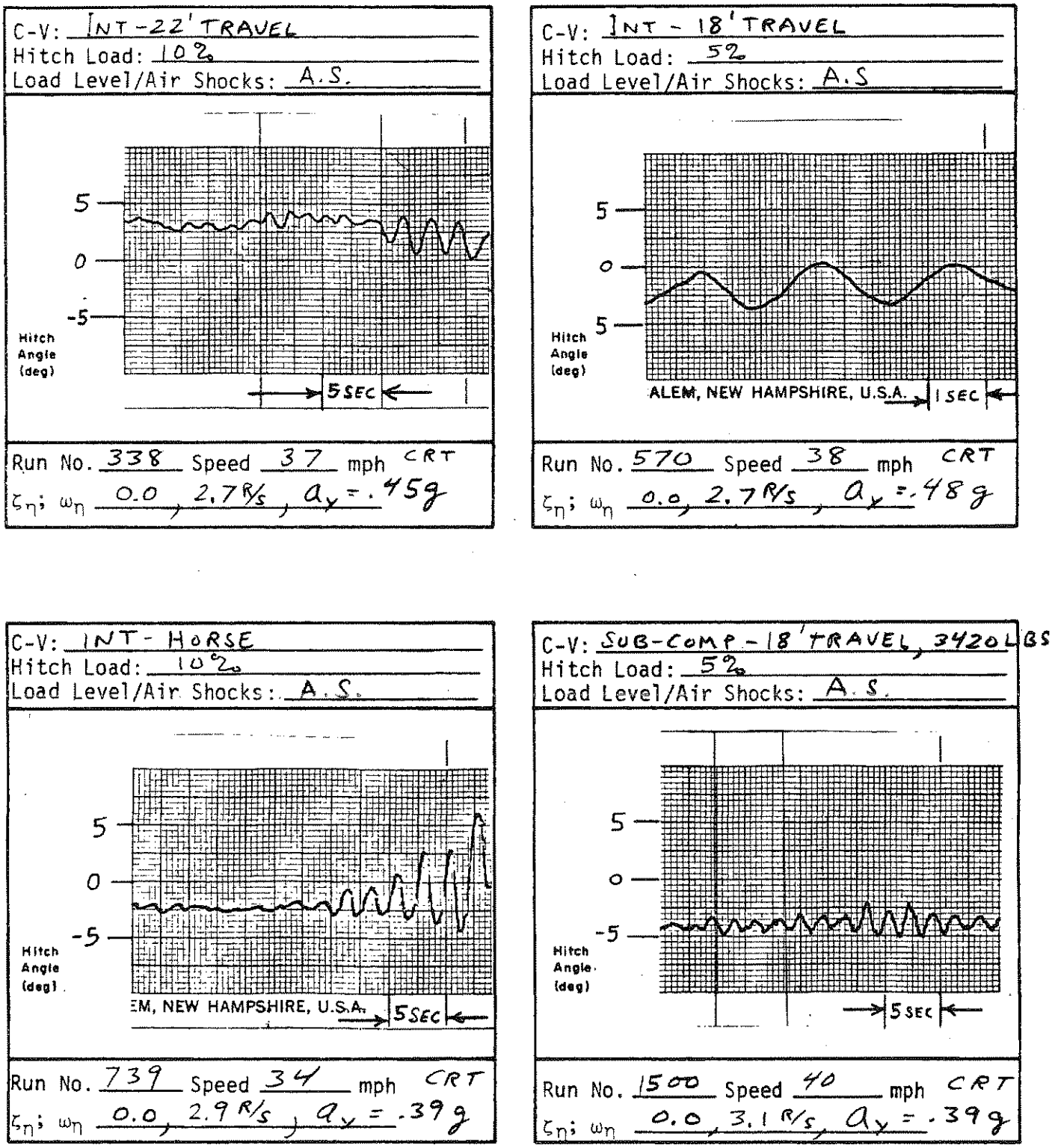


Figure E-5. Trailer Swing Damping Tests in Constant Radius Circle Test at High a_y, No Pulse Steer

TABLE E-2

TRAILER DAMPING CHANGE DUE TO CORNERING

Run No.	Configuration (No L.L. used, only A.S.)	Speed for Zero Damping at Approx. 0.4 g Cornering	Speed for Zero Damping at Approx. 0 g Cornering
338	Intermediate-22' Travel, 10% HL	37 mph	76 mph
570	Intermediate-18' Travel, 5% HL	38 mph	49 mph
739	Intermediate-Horse, 10% HL	34 mph	80 mph
1500	Subcompact-18' Travel, 5% HL at 3420 lb	34 mph	no data

APPENDIX F

TOW CAR STABILITY FACTOR DATA

This appendix presents step steer and constant radius circle test results for a representative set of combination vehicles from the test program. Since there were over 190 total data plots, the selection was based on the higher hitch load configurations as these show the more nonlinear behavior which, in some cases, leads to a jackknife.

SUMMARY OF STABILITY FACTOR DATA

The complete set of reduced results is presented in Figure F-1. This includes the measured values for left hand (LH) and right hand (RH) terms and also the lateral acceleration level producing neutral steer (K = 0). This latter measure is quite significant since towing heavy trailers with ordinary passenger cars results in highly nonlinear understeer characteristics, even at the lower lateral acceleration levels.

STABILITY FACTOR PLOTS

Figures F-1 to F-3 present results of the step steer test (SST) and the constant radius circle test (CRT) for each tow car and trailer combination. Both tests are used to determine the tow car alone and combination vehicle understeer gradient. In the SST, plots are made of turn radius, R, versus velocity squared, U_o^2. Stability factors are determined from these plots by taking the slope of R versus U_o^2. In standard SAE notation (Ref. F-1) stability factor is proportional to the understeer/oversteer gradient, expressed in deg/g, which is:

$$\kappa_{SAE}(\text{deg/g}) = 1847(\ell_1)K(\text{sec}^2/\text{ft}^2) \qquad \text{(F-1)}$$

when wheelbase, ℓ_1, is in feet. The steady-state turn radius or radius of curvature, R, is actually determined by measuring the velocity and dividing by the steady-state yaw velocity, r_{ss}. The mathematical relationship is given by:

$$R = \left.\frac{U_o}{r}\right|_{ss} = \frac{\ell_1}{\delta_w} + \frac{\ell_1}{\delta_w} KU_o^2 \qquad \text{(F-2)}$$

TABLE F-1. SUMMARY OF STABILITY FACTOR DATA

CV Configuration	Percent Hitch Load / Percent Load Leveling	Turn Direction	K_{SF} at $a_y = 0$ SST deg/g	K_{SF} at $a_y = 0$ CRT deg/g	a_y at $K_{SF} = 0$ SST g	a_y at $K_{SF} = 0$ CRT g	a_y, U_o for Jackknife SST
Intermediate Car Alone	Initial	LT RT	4.2	5.3 4.7	>.5	>.5 >.5	
	After test	LT	5.9	5.6	>.5	>.5	
Intermediate Utility	10% HL	LH RH	↑	4.9 4.2		>.5 >.5	
	20% HL	LH RH	at 50 mph only	4.4 3.5		>.5 >.5	
Intermediate Camper	21% HL	LH RH		4.7 3.8		>.5 >.5	
	16% HL	LH RH		5.3 4.3		>.5 >.5	
	10% HL	LH RH	↓	5.4 4.0		>.5 >.5	
Intermediate 18 ft Travel 3000 lb wgt	13% HL, +25% LL	LH RH	4.2 3.4	3.2 3.5	>.31 >.36	0.47 0.35	
	13% HL, No LL	LH RH	4.6 4.6	4.5 4.3	>.32 >.37	>.5 >.5	
Intermediate 18 ft Travel 3880 lb wgt	20% HL, -25% LL	LH RH	2.6 1.8	2.0 1.5	>.38 0.37	0.34 0.35	>.42 g, 46 mph
	20% HL, +25% LL	LH RH	1.7 1.7	1.9 0.94	>.41 0.35	0.24 0.21	>.38 g, 42 mph
	10% HL, +25 % LL	LH RH	3.2 3.2	2.9 2.9	>.35 0.30	>.5 0.38	
Intermediate 19 ft Travel	15% HL, +25% LL	LH RH	1.4 0.43	1.8	>.29 >.26	0.4	
	15% HL, -32% LL	LH RH	1.9 1.3		>.32 >.33		
Intermediate 22 ft Travel 4000 lb wgt	10% HL, 0% LL	LH RH	↑	3.5 3.0		0.44 0.38	
	10% HL, No LL	LH RH		4.8 3.8		>.5 >.5	
	10% HL, +25% LL	LH RH	at 50 mph only	4.7 3.9		0.30 0.28	
	20% HL, +25% LL	LH RH	↓	0.9 0.9		0.33 0.26	
Intermediate 27 ft Travel	15% HL, 0% LL	LH		0		0.15	
	15% HL, +25% LL	LH	-1.1	≅.0	0.0	0.18	>.47 g, 44 mph
	10% HL, +25% LL	LH	0.8	1.8	0.16	0.26	>.32 g, 46 mph
	15% HL, -20% LL	LH RH	-.49		0.0		>.30 g, 46 mph
	10% HL, -15% LL	LH	2.4		0.27		
Intermediate Boat	13.3% HL, No LL	LH	3.3	3.6	>.30	>.5	
	15% HL, No LL	LH	4.6		>.29		
	15% HL, +25% LL	LH	2.1	2.8	>.31	0.48	

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TABLE F-1 (Concluded)

CV Configuration Percent Hitch Load Percent Load Leveling		Turn Direction	K_{SF} at $a_y = 0$ SST deg/g	K_{SF} at $a_y = 0$ CRT deg/g	a_y at $K_{SF} = 0$ SST g	a_y at $K_{SF} = 0$ CRT g	a_y, U_o for Jackknife SST
Intermediate Horse 5800 lb wgt	15% HL	LH RH	2.2 1.9		>.31 >.35		
	10% HL	LH RH	3.5 2.1	3.1	>.27 >.33	>.5	
Compact Car Alone	Initial	LH	6.2	6.0	>.5	>.5	
	After test	LH	6.6		>.5		
Compact 22 ft Travel	5% HL, No LL	LH	5.9	4.2	>.43	>.5	
	7.5% HL, No LL	LH	6.0	3.8	>.42	>.5	
	10% HL, -29% LL	LH	2.3	1.5	>.41	>.5	
	12.5% HL, -6% LL	LH	0.70	0.35	0.40	0.25	>.6 g, 43 mph
	15% HL, -7% LL	LH	≅.0	0.0	0.25	0.0	>.5 g, 40 mph
	17.5% HL, +4% LL	LH	≅.0	≅.0	0.16	0.10	>.5 g, 40 mph
	15% HL, +17% LL	LH	≅.0	≅.0	0.20	0.12	>.45 g, 39 mph
	15% HL, +17% LL Coast down test	LH	≅.0		0.0		>.45 g, 37 mph
Compact Boat 2275 lb wgt	26% HL, +28% LL	LH	1.8	1.9	0.40	0.25	>.55 g, 41 mph
	Coast down test	LH	1.7		0.35		>.44 g, 38 mph
Compact Horse 4000 lb wgt	10% HL	LH	4.9		>.5		
Compact 18 ft Travel	15% HL, +23% LL	LH	0.0		0.0		>.43 g, 38 mph
	Coast down test	LH	1.4		0.22		>.46 g, 39 mph
Compact 27 ft Travel	10% HL, +15% LL	LH	-.68		0.0		>.38 g, 36 mph
Sub-compact Car Alone		LH	4.1	2.7	>.5	>.5	
Sub-compact Boat	0% HL, No LL	LH	4.0	2.2	>.5	>.5	
	5% HL, No LL	LH	2.9	1.3	>.5	>.5	
	5% HL, 0% LL	LH	2.1	1.4	0.5	>.5	>.48 g, 44 mph
	10% HL, +32% LL	LH	1.4	0.0	0.30	0.0	>.41 g, 38 mph
	15% HL, +21% LL	LH	≅0	-.61	0.17	0.0	>.35 g, 34 mph
Sub-compact 18 ft Travel 3420 lb wgt	5% HL, No LL	LH	2.7	1.6	>.5	>.5	
	7.5% HL, No LL	LH	2.1		>.5		>.5 g, 43 mph
Sub-compact Utility	10% HL	LH	3.5	2.6	>.5	>.5	

where δ_w is the front steer angle required to maintain a given fixed turn radius.

For a fixed steering wheel angle input, measurements taken of steady state yaw velocity at increasing incremental speeds are then plotted versus speed squared. This results in straight line plots as long as the vehicle response remains linear. The stability factor, K, and the effective front steer angle are determined directly from the plot as:

$$K = \text{Slope/Intercept} \qquad \text{(F-3)}$$

$$\delta_{w_{eff}} = \text{Wheelbase/Intercept} \qquad \text{(F-4)}$$

where the intercept is obtained by extrapolating the straight line to $U_o^2 = 0$. Note the front steer angle is referred to as "effective" since a constant steering wheel angle does not produce a constant front steer angle.

Stability factor can also be measured in the nonlinear higher g cornering region by taking the instantaneous slope at any speed, multiplying by wheelbase, and then dividing by the intercept at zero speed, i.e.,

$$K = \frac{\text{slope} \times \ell_1 \times 1847}{\text{intercept}} \text{ in deg/g} \qquad \text{(F-5)}$$

A second technique commonly used to determine stability factor is the constant radius circle method described in Ref. F-2. For nonlinear systems this method appears preferable to the SST since no transients are present and smaller and smoother transitions to higher lateral accelerations are made. This is especially important when trying to determine the lateral acceleration for neutral steer, $a_{y_{k=0}}$, or the speed for jackknife. On the other hand it is very hard on tire shoulder wear, has engine power limitations, requires at least a 500 ft square pad area (for 200 ft radius circle), and develops trailer stability interactions. However with this procedure the steering wheel angle is plotted versus lateral acceleration to provide the understeer gradient directly, i.e.,

$$\frac{\delta_{s_w}}{G}\,(\text{deg}) = \frac{57.3\,\ell_1}{R} + \kappa\, a_y \qquad \text{(F-6)}$$

Where G = steering ratio (>1)

a_y = lateral acceleration, g's

κ = slope (deg/g)

$\frac{57.3\,\ell_1}{R}$ = intercept (deg)

REFERENCES

F-1 Vehicle Dynamics Terminology, SAE J670d, July 1975.

F-2 Passenger Car and Light Truck Steady State Directional Control Response Test Procedures, SAE Proposed Recommended Practice XJ266, 1977.

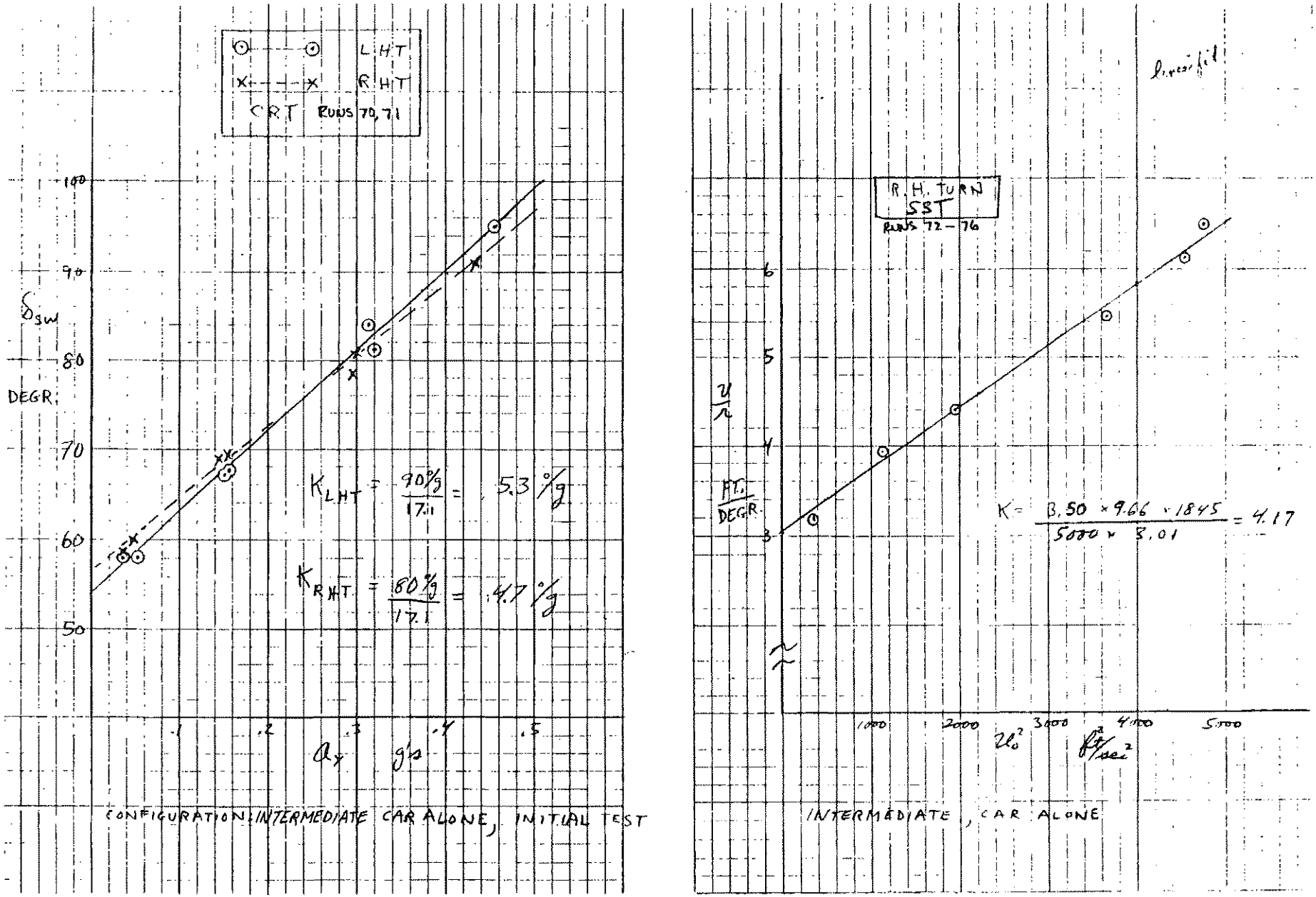
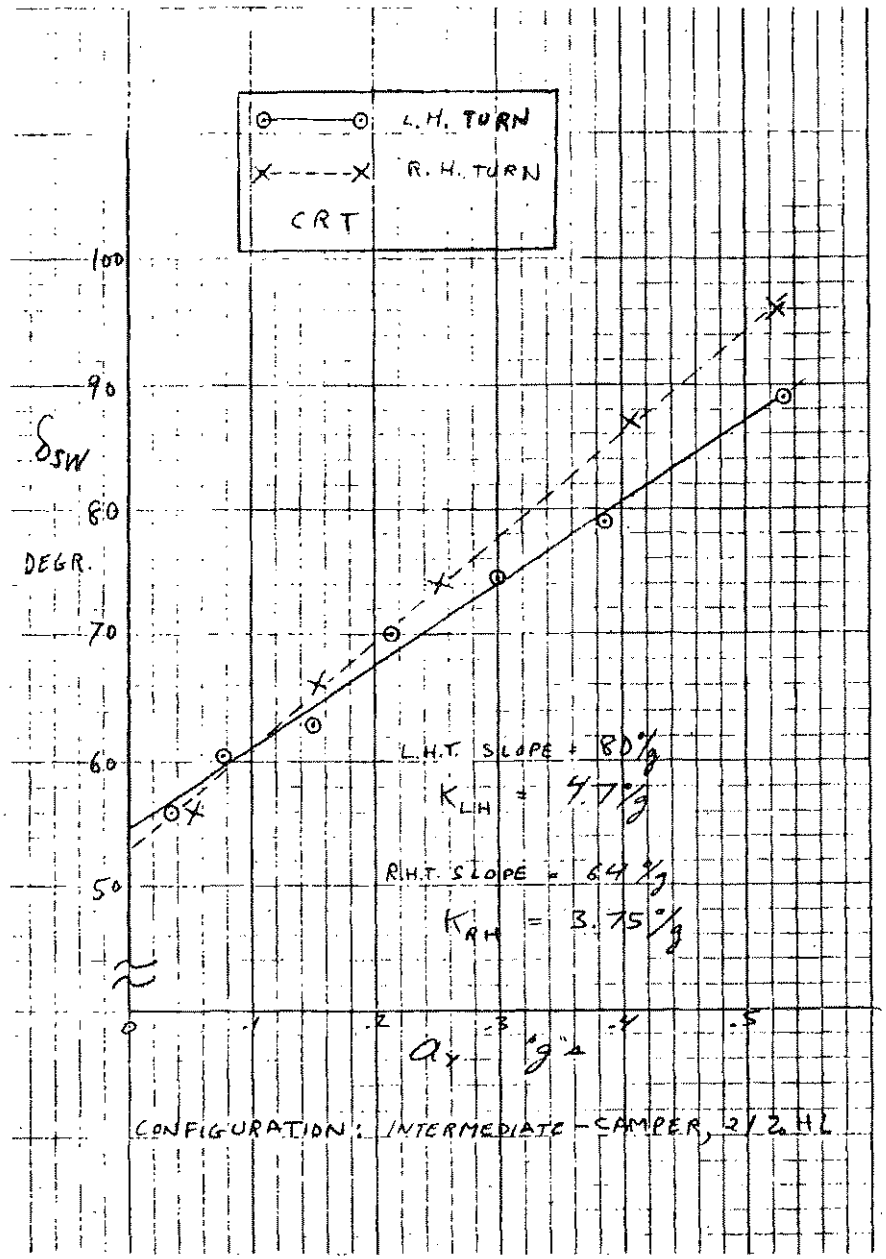
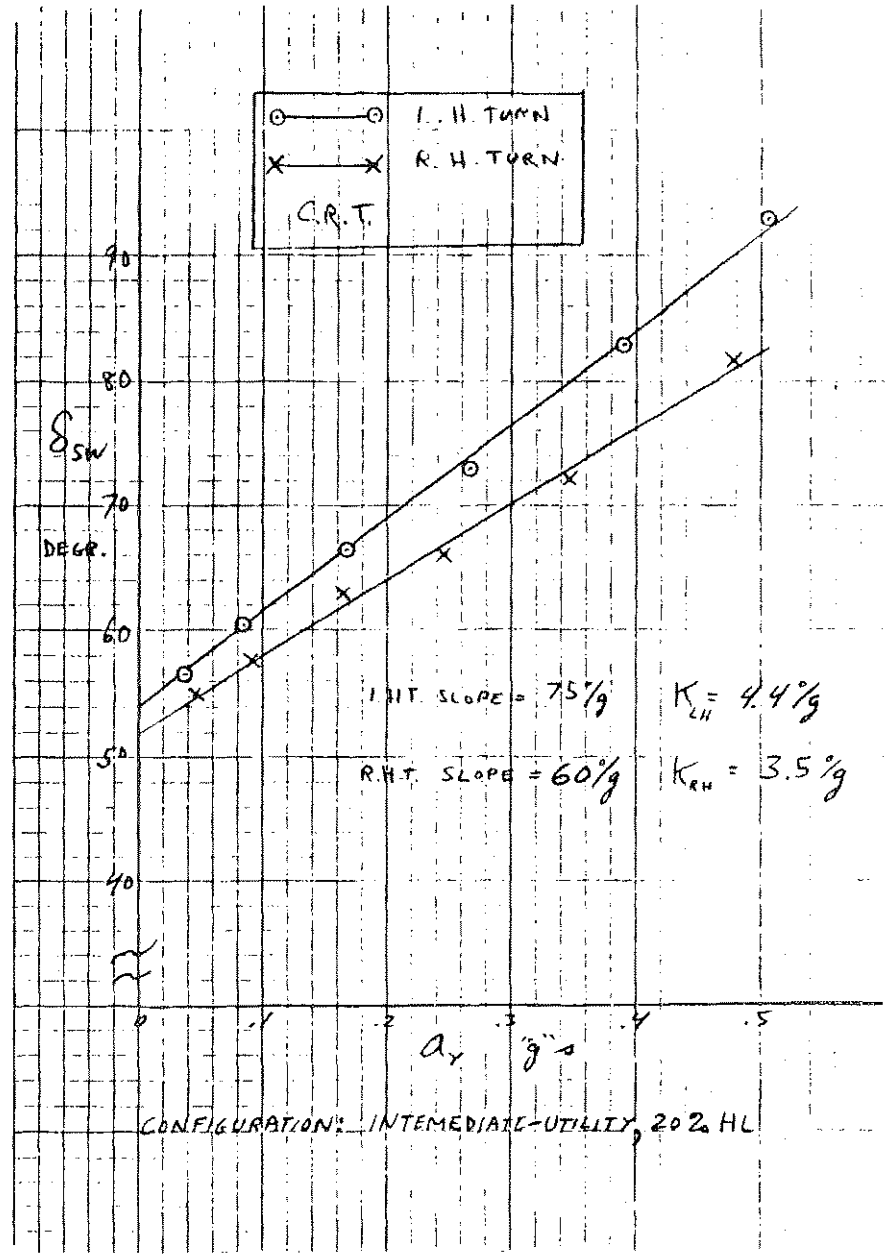


Figure F-1. Stability Factor Plots for Intermediate Tow Car and Combinations





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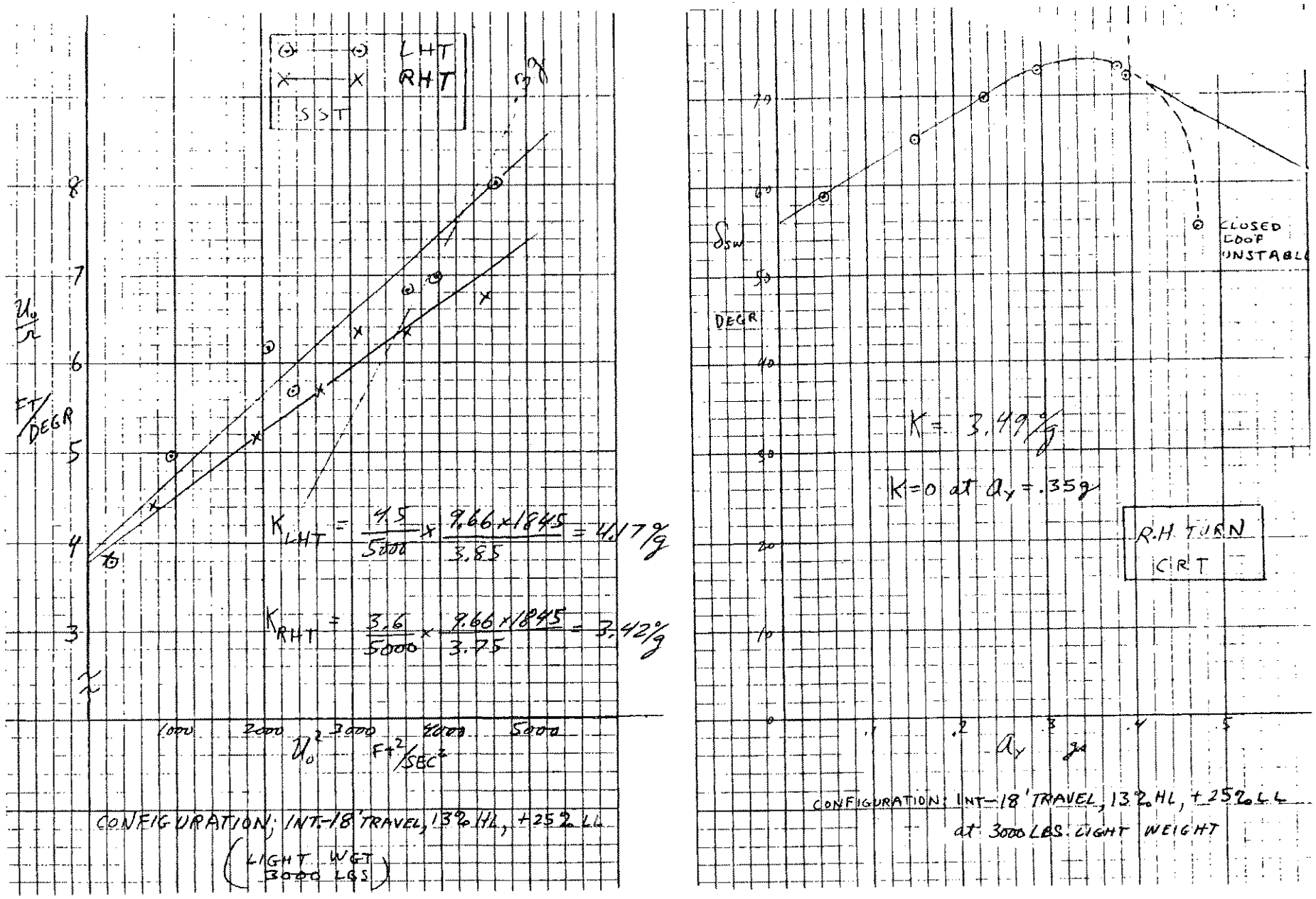

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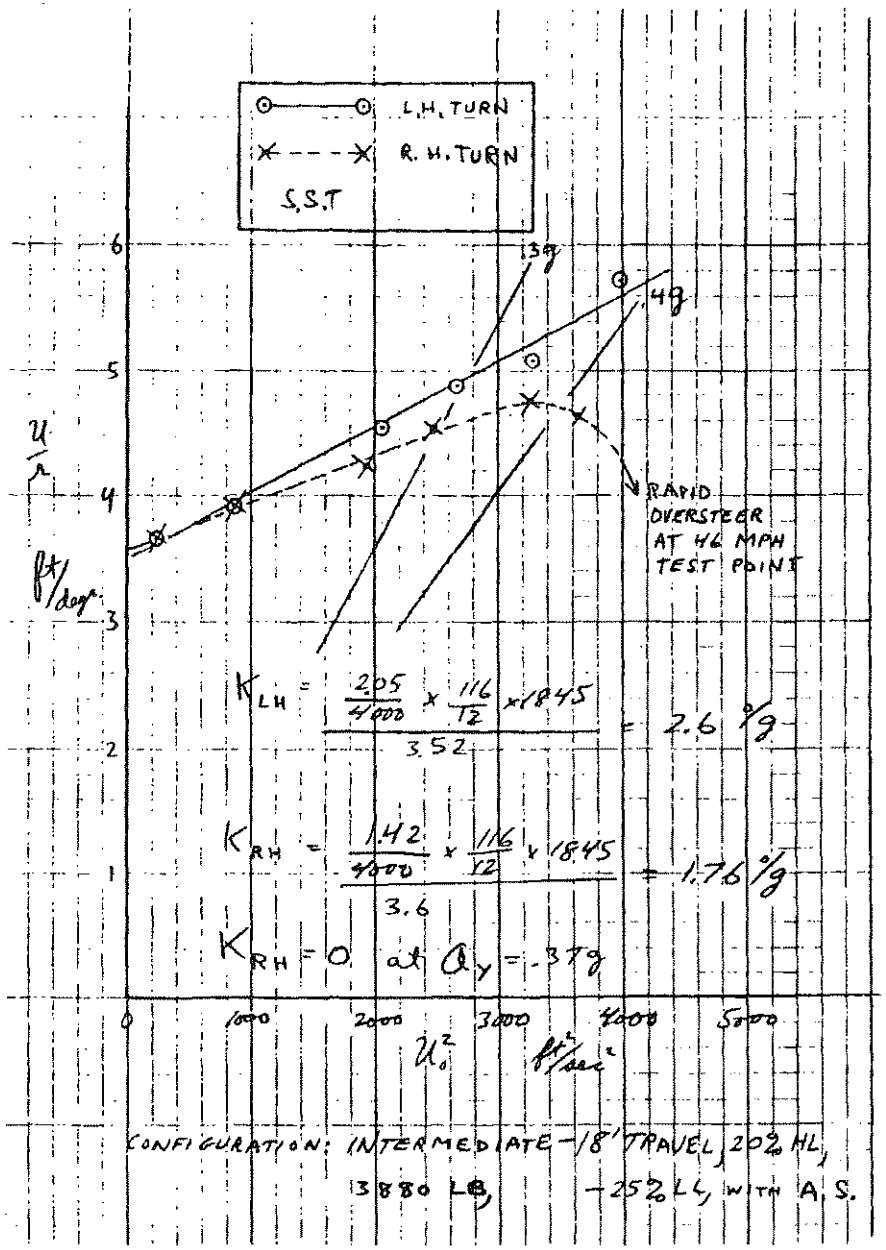

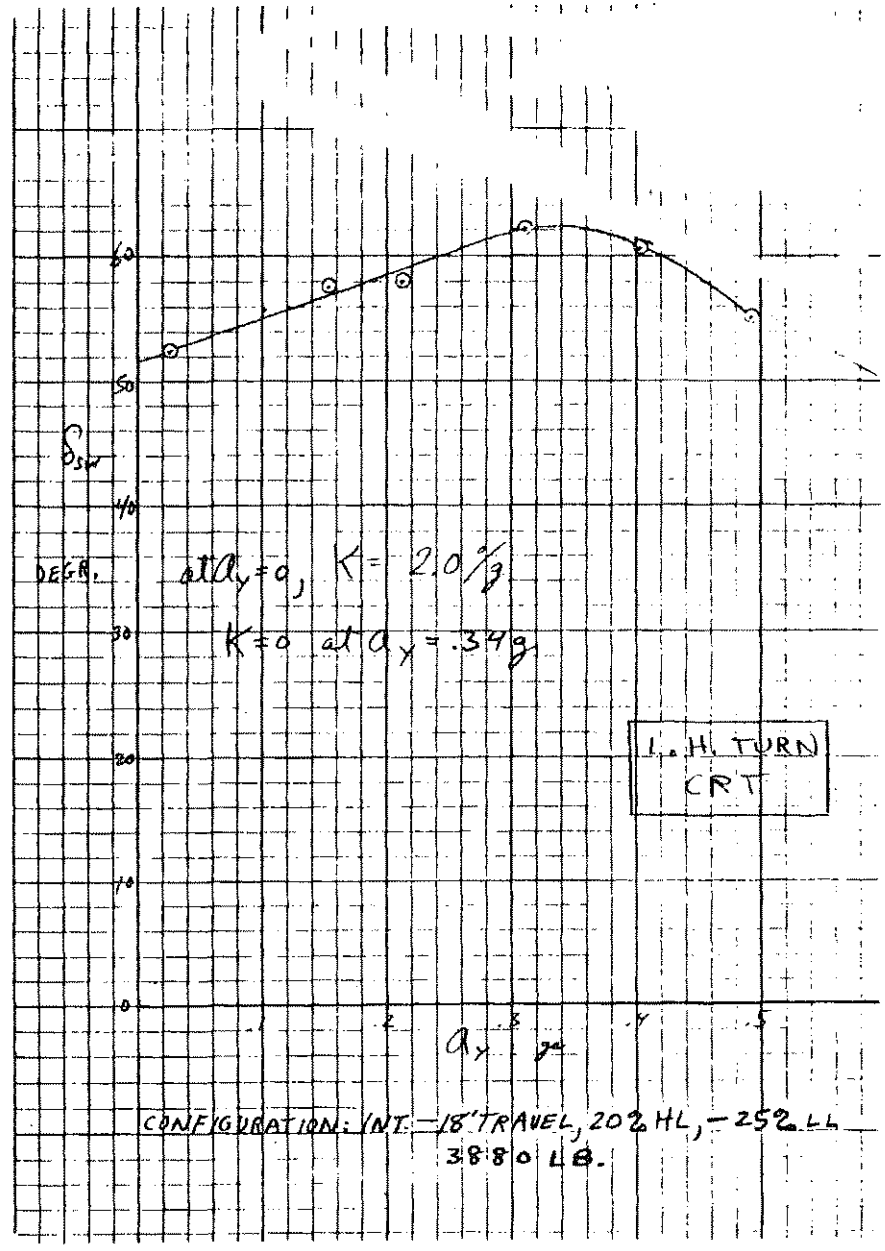

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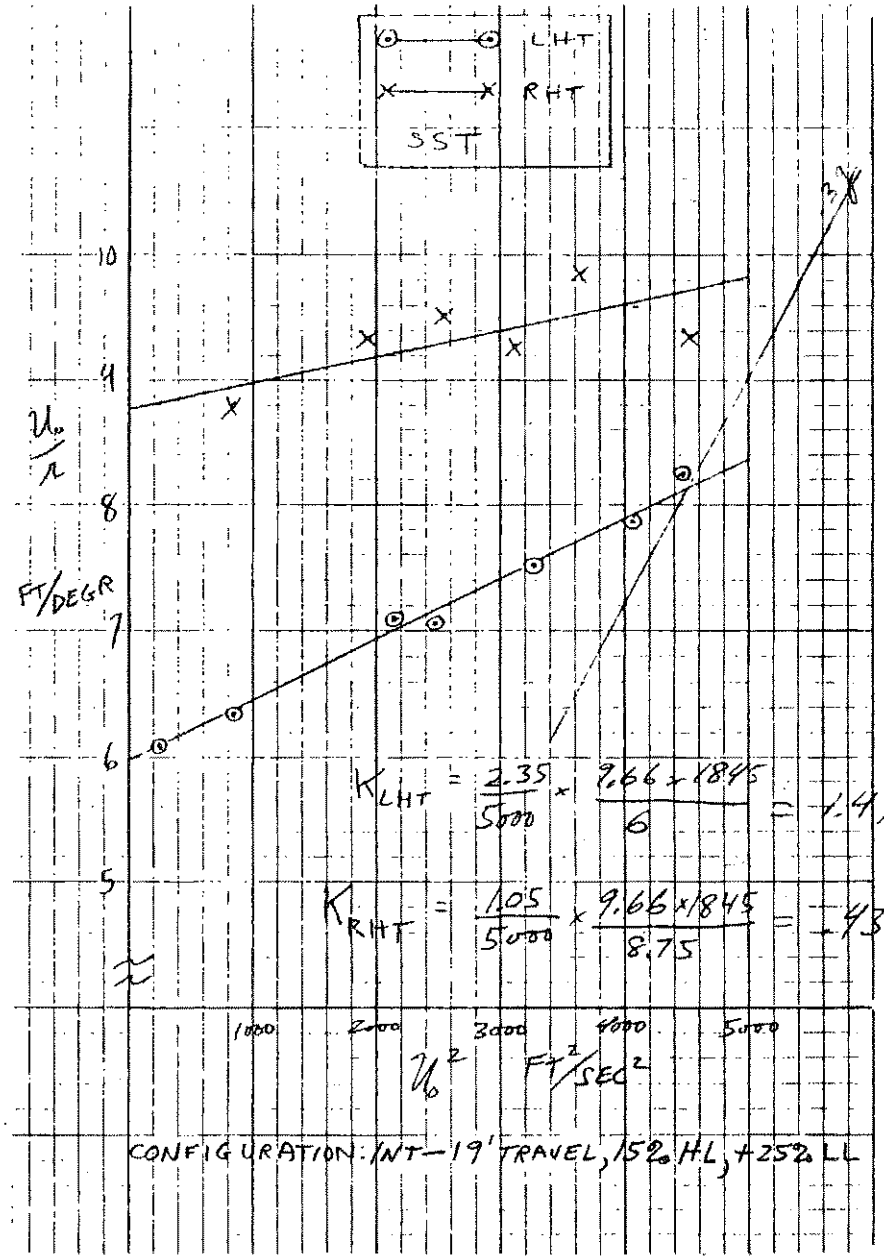

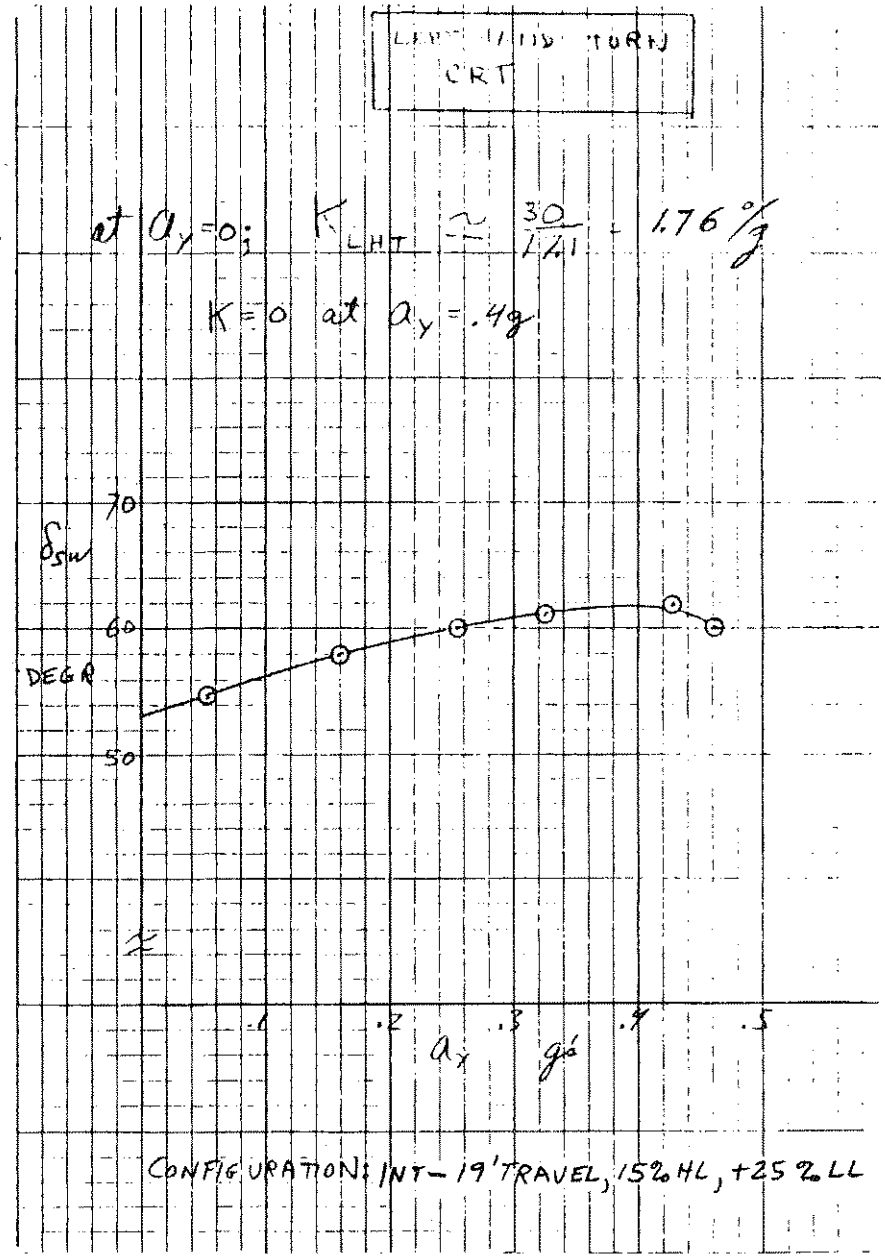

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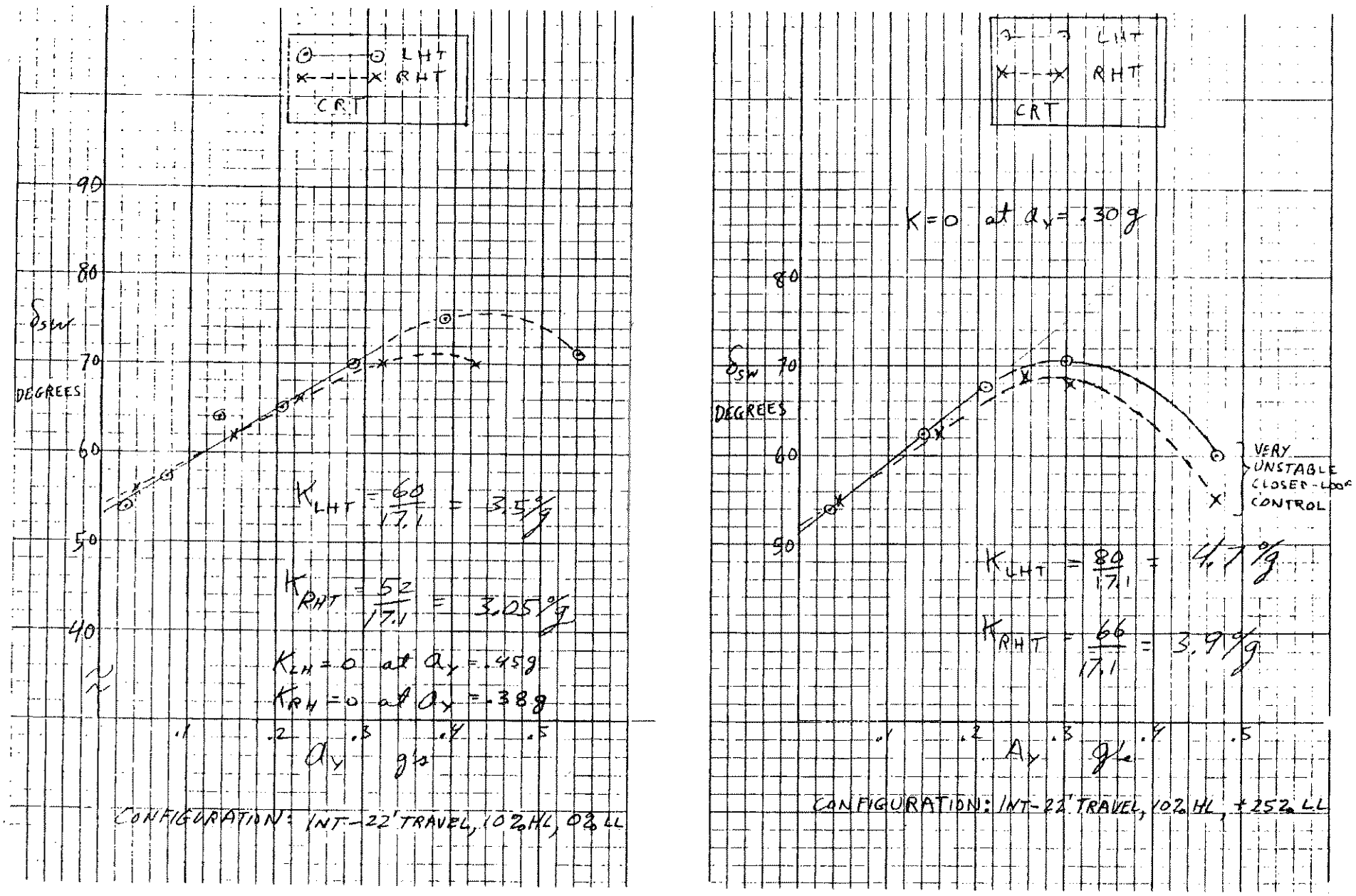

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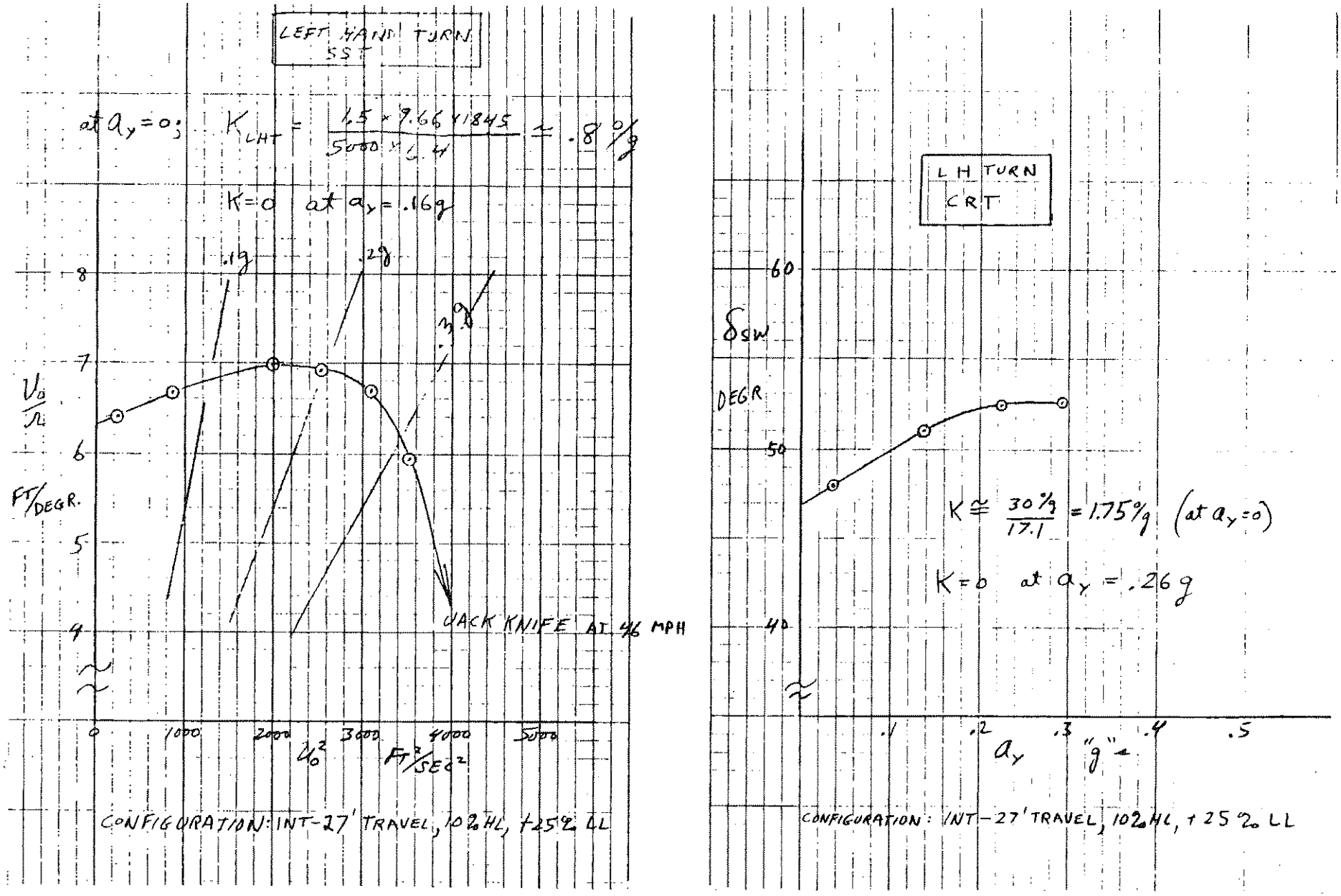

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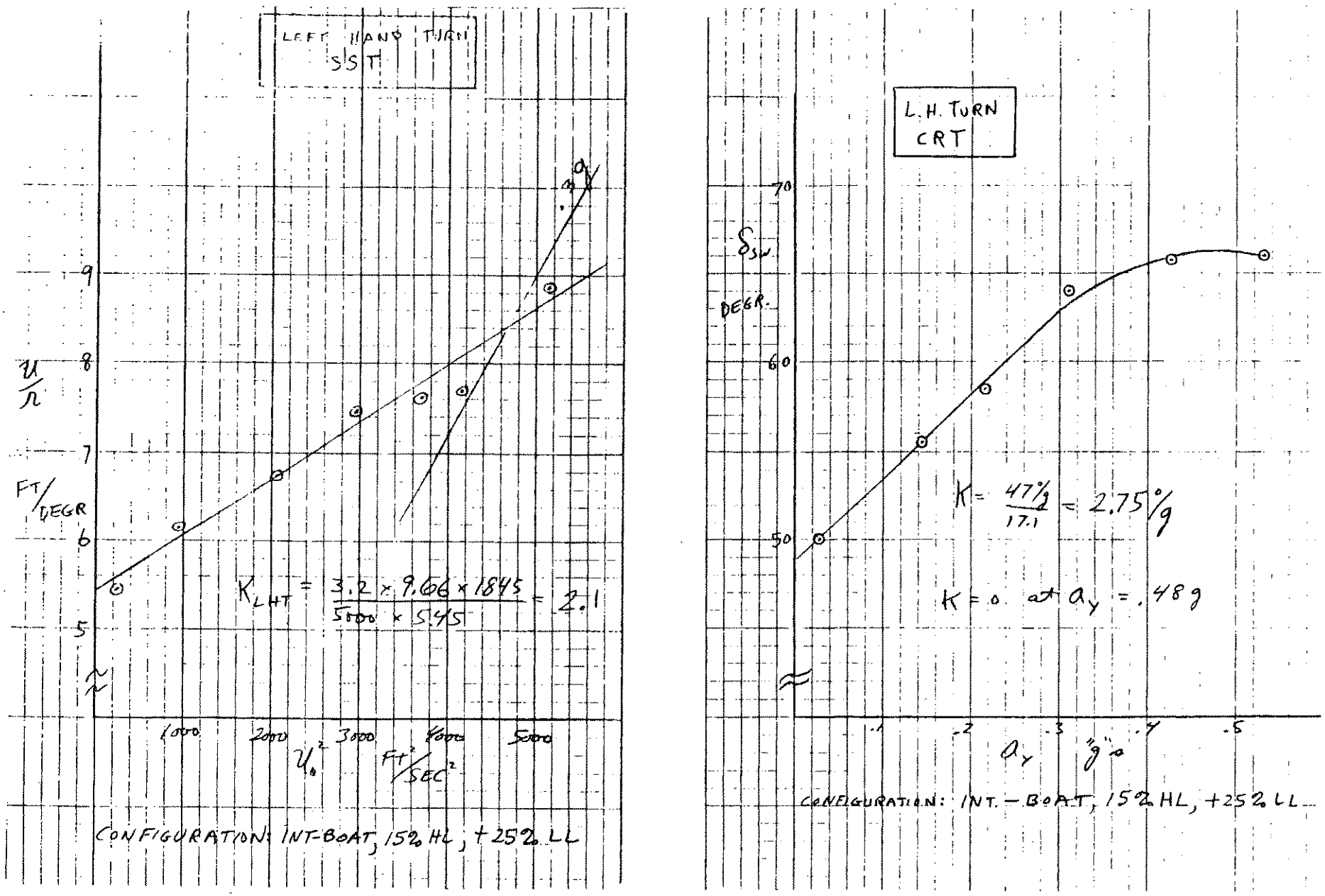

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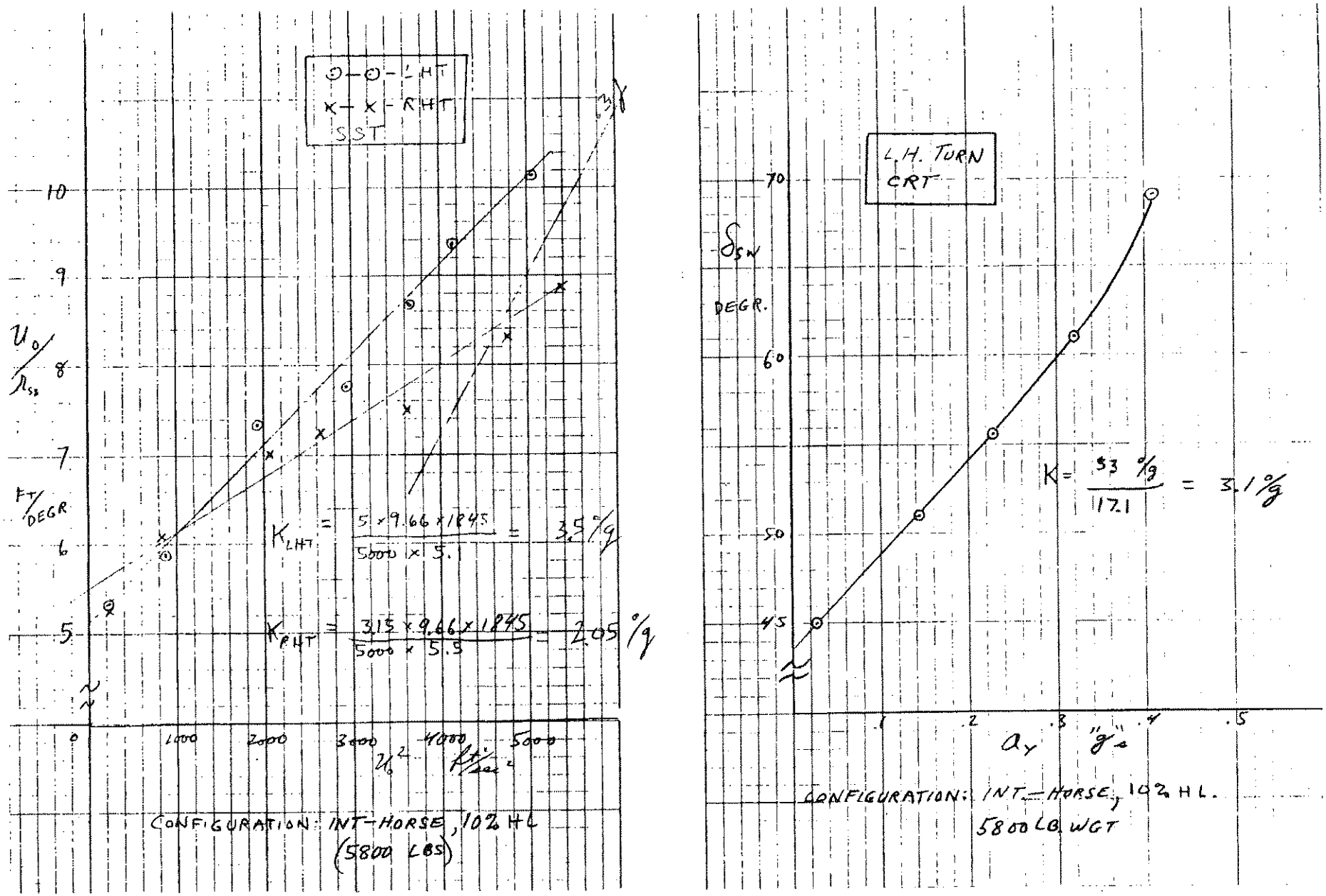

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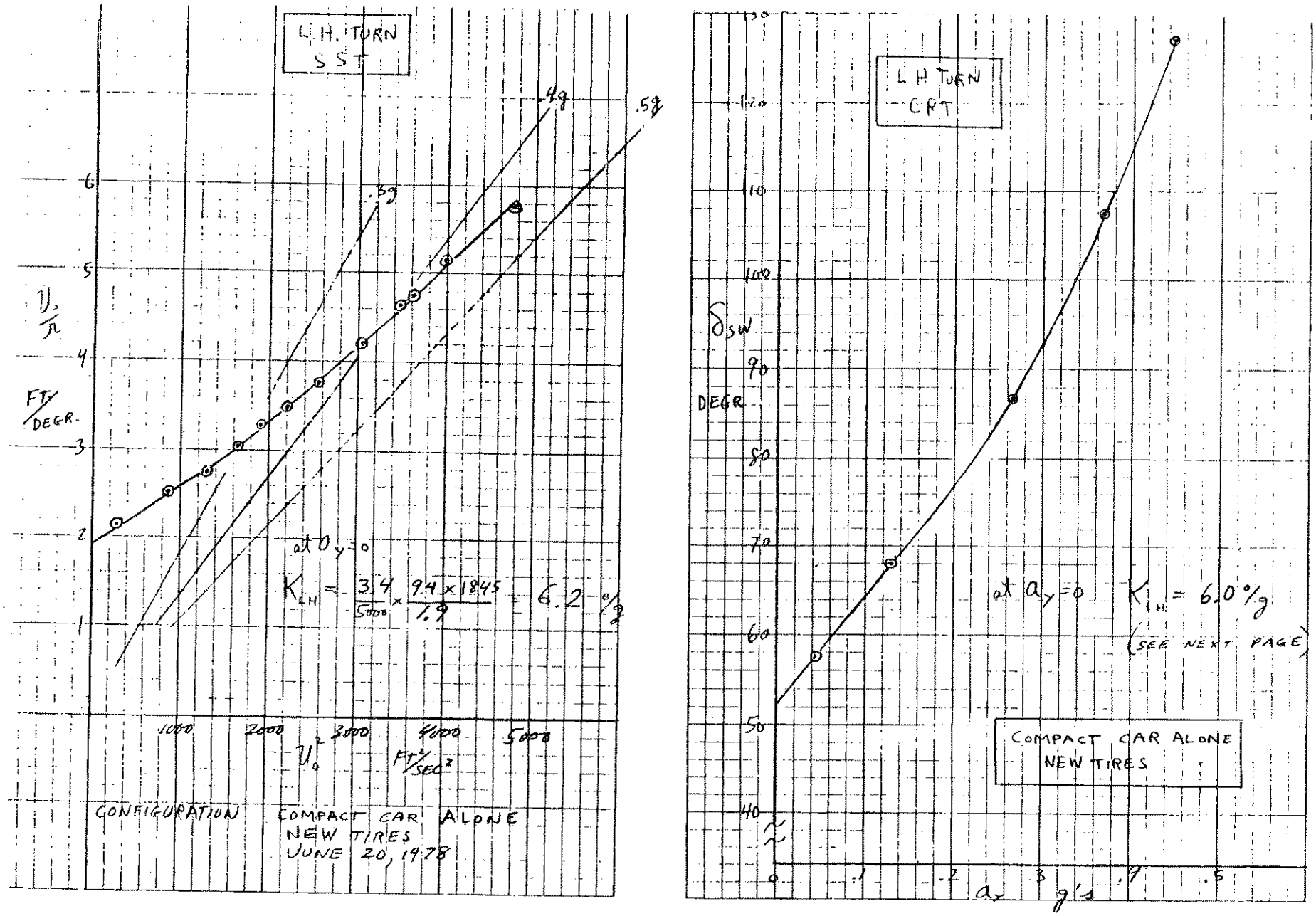
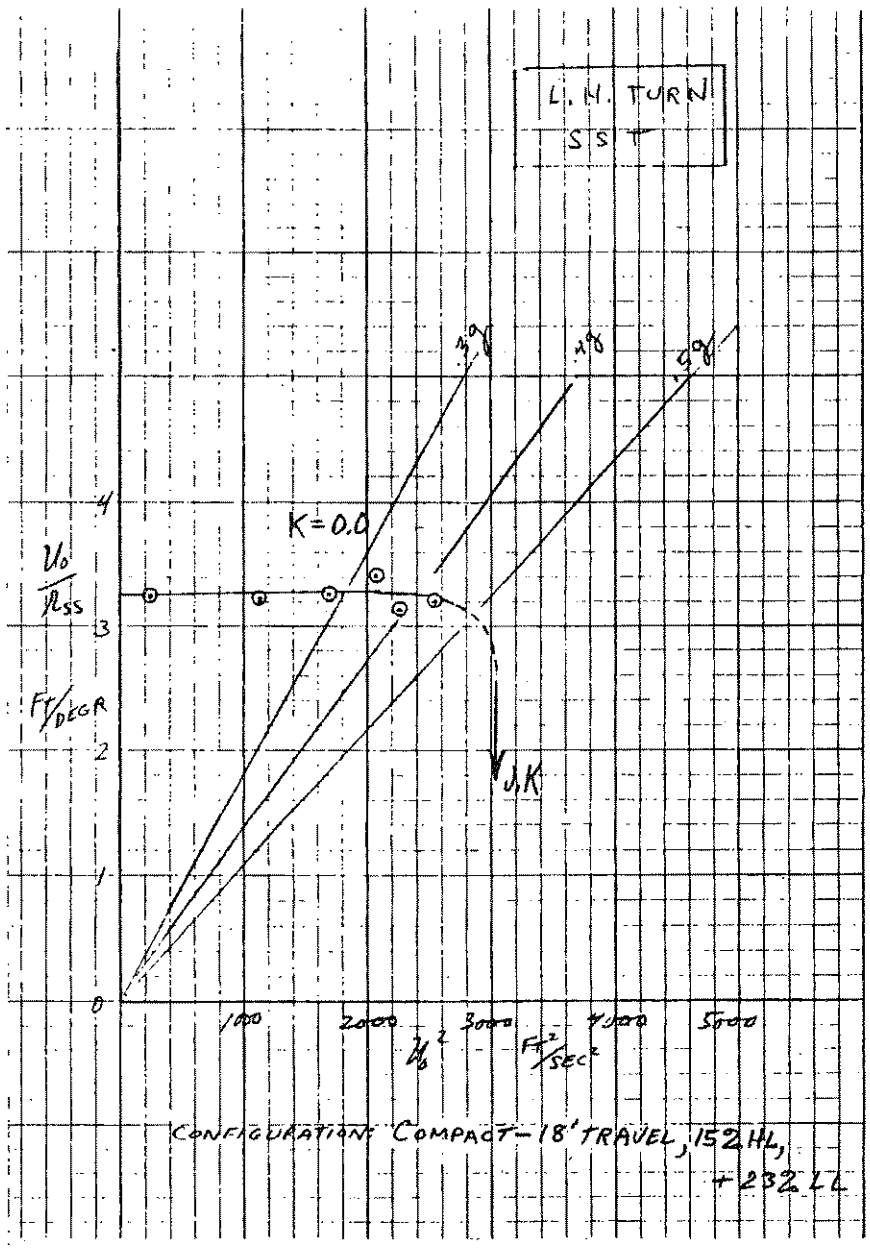
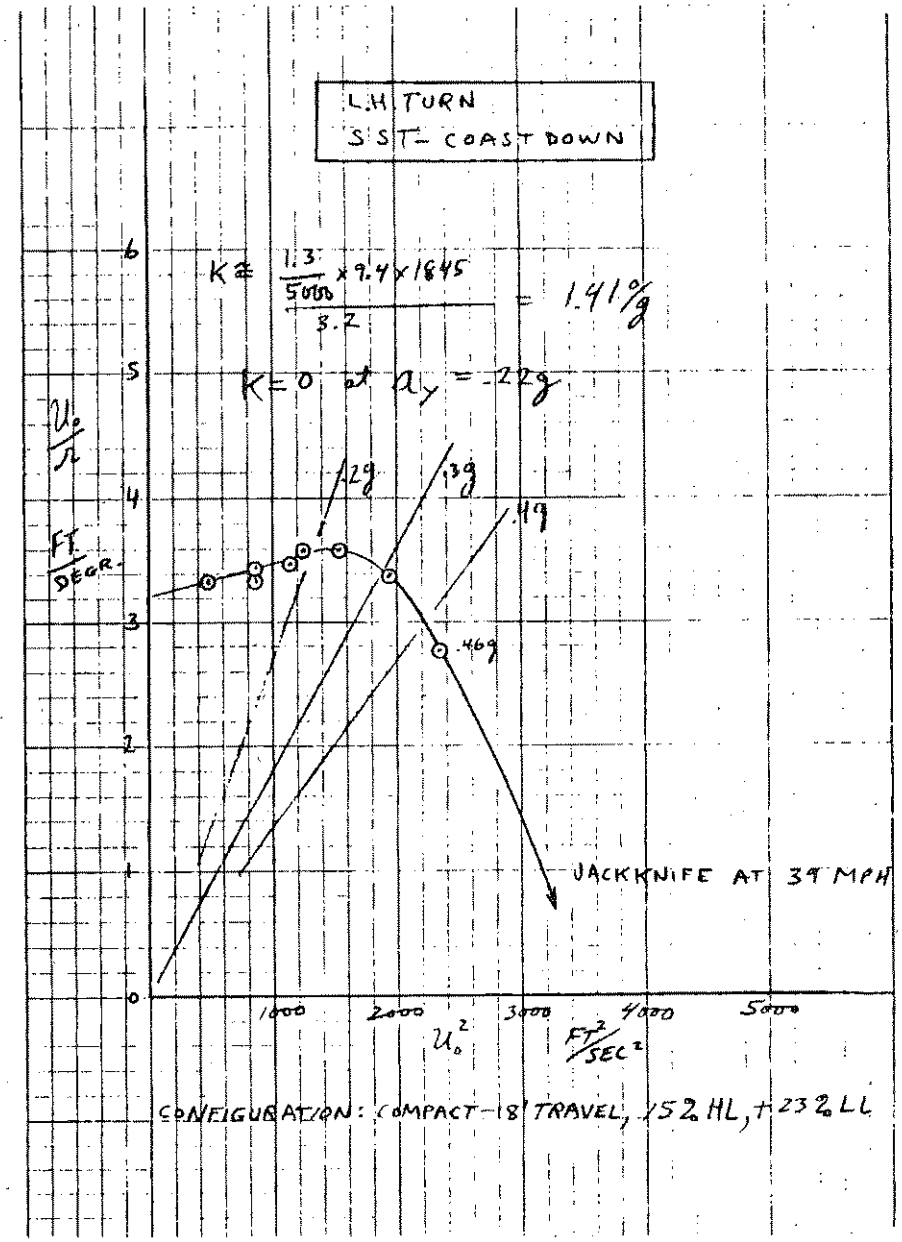


Figure F-2. Stability Factor Plots for Compact Tow Car and Combinations





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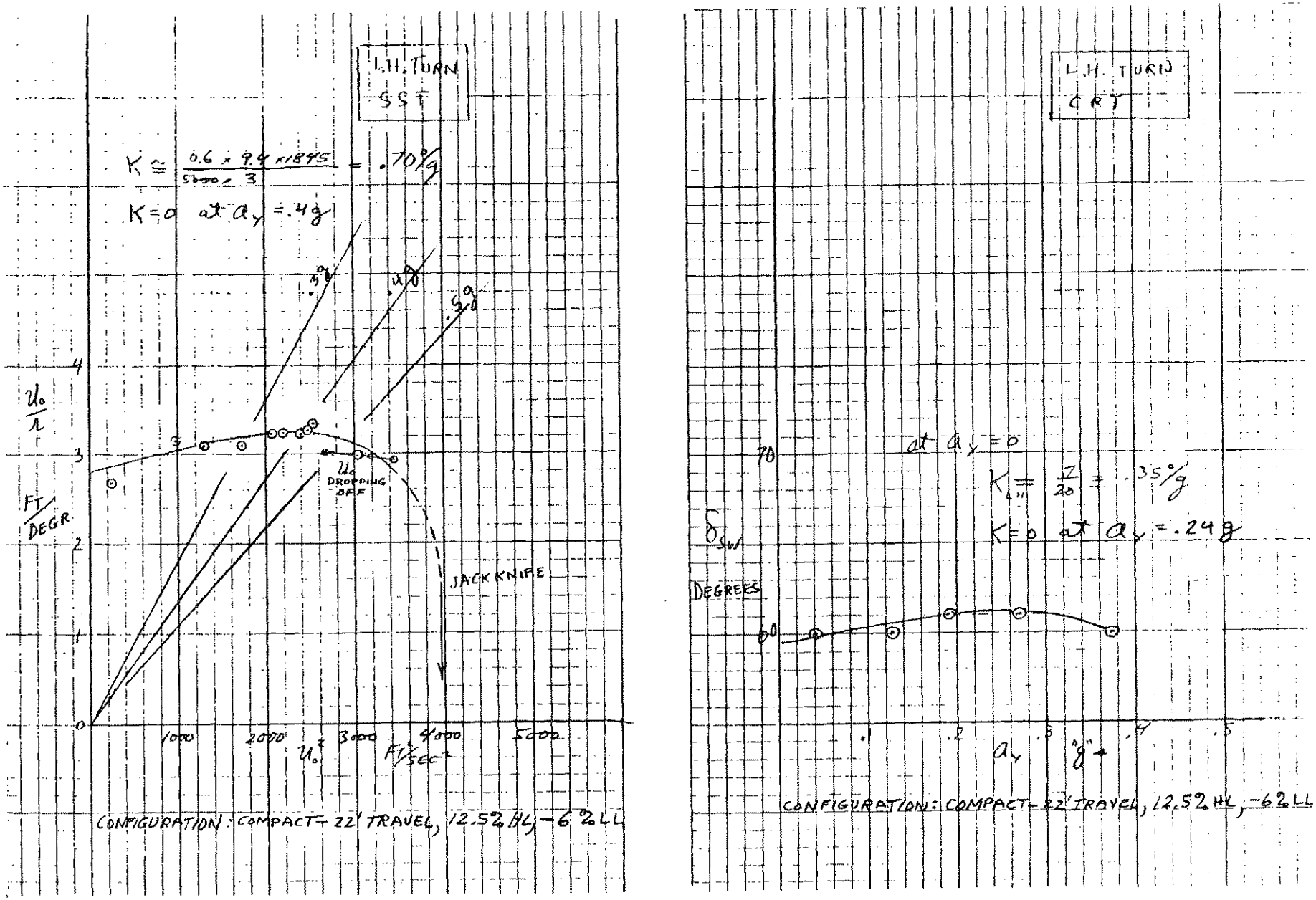

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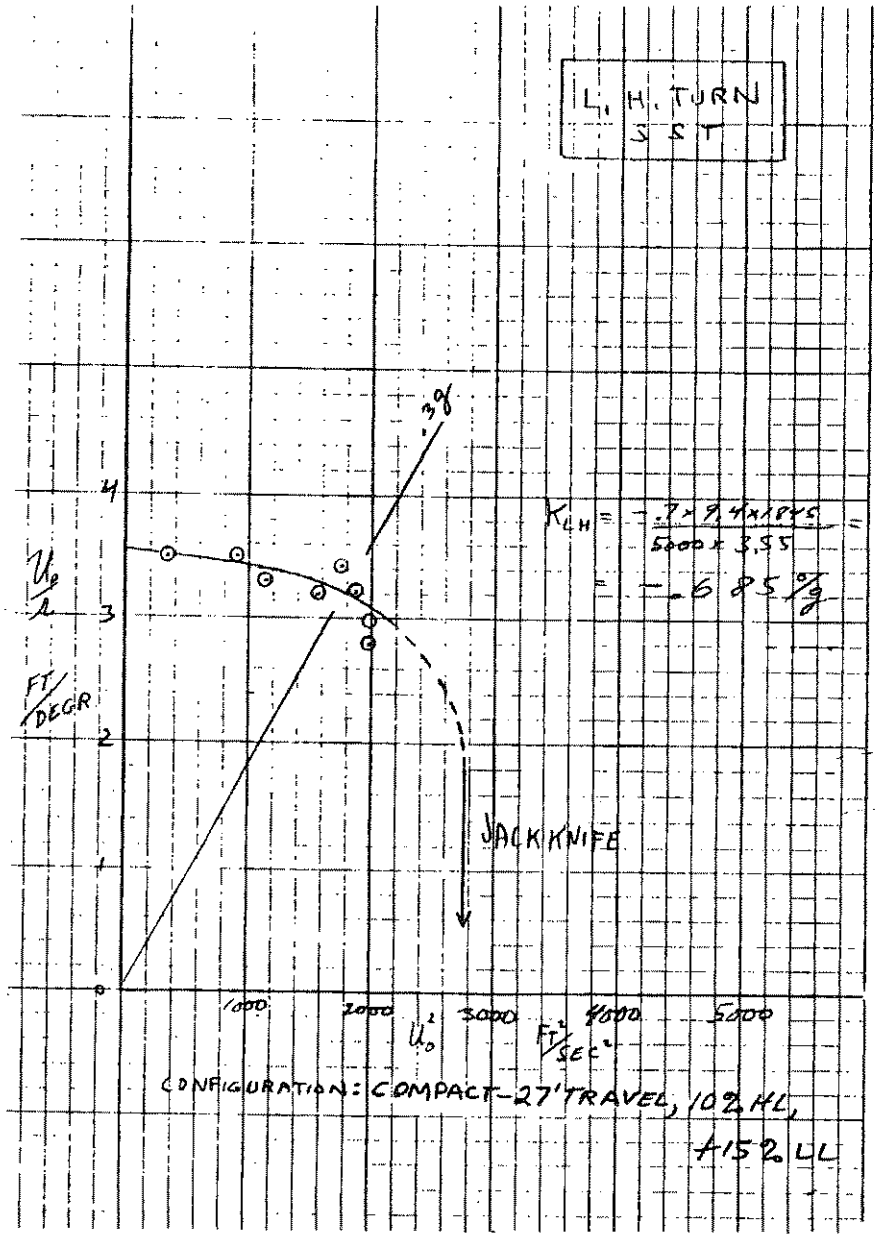

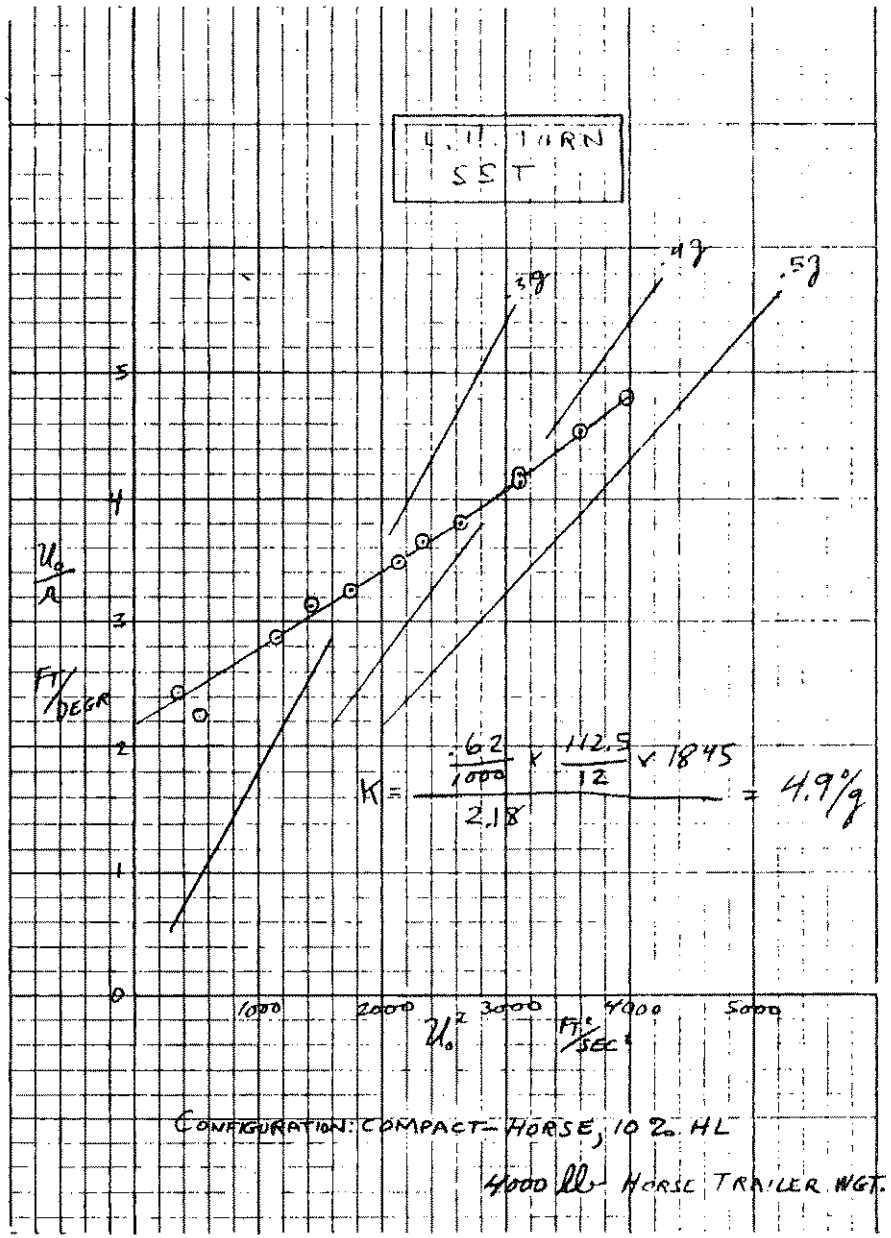

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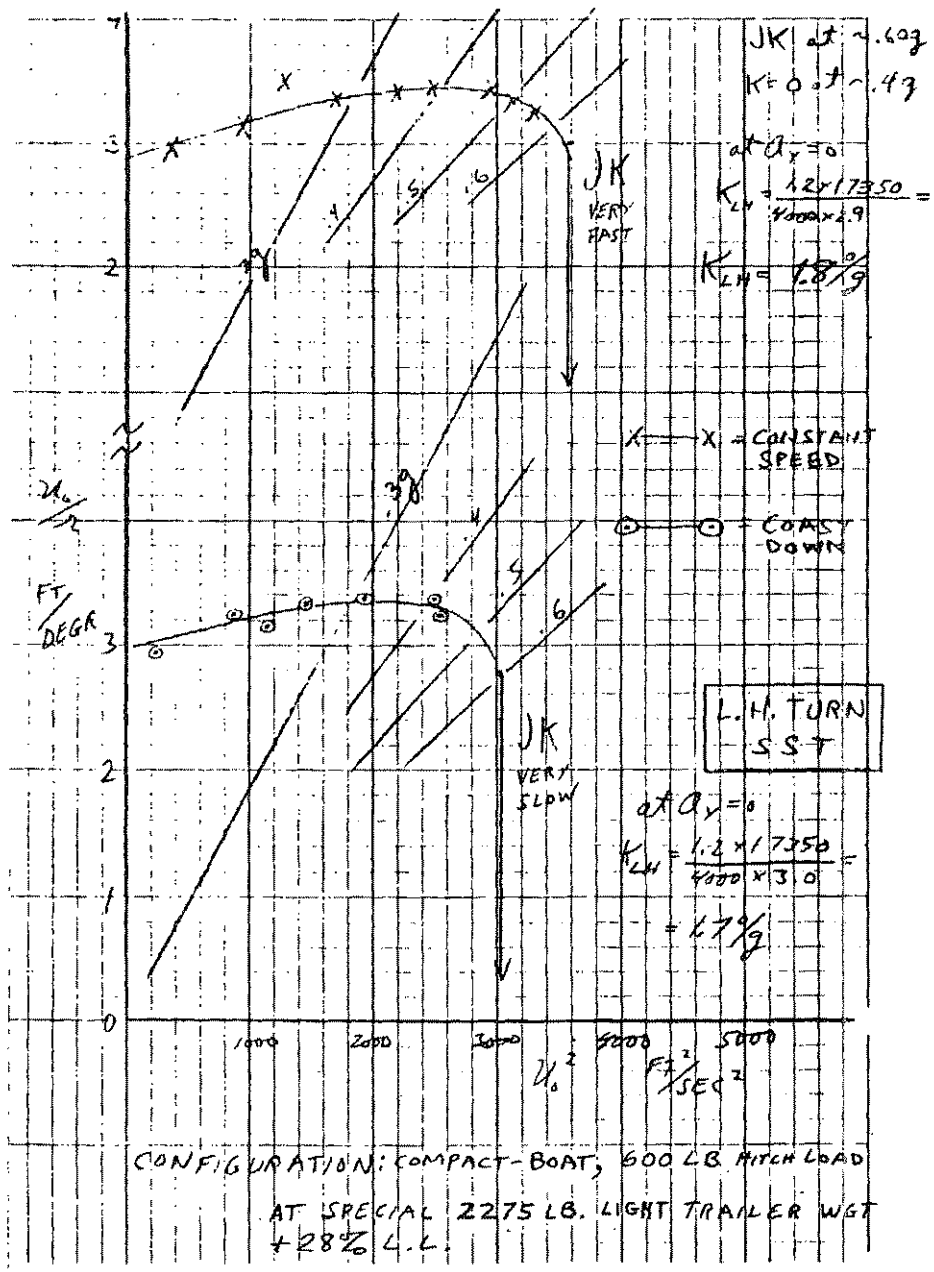

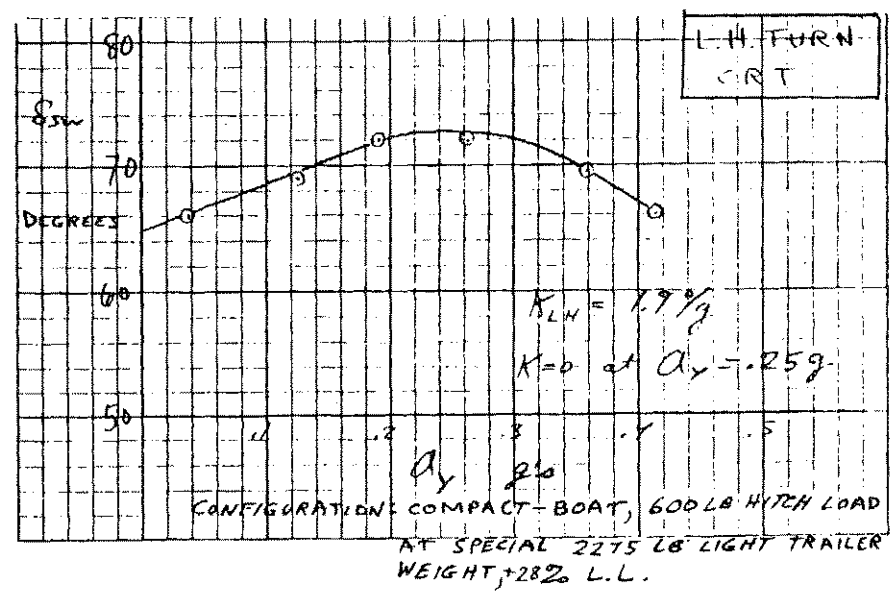

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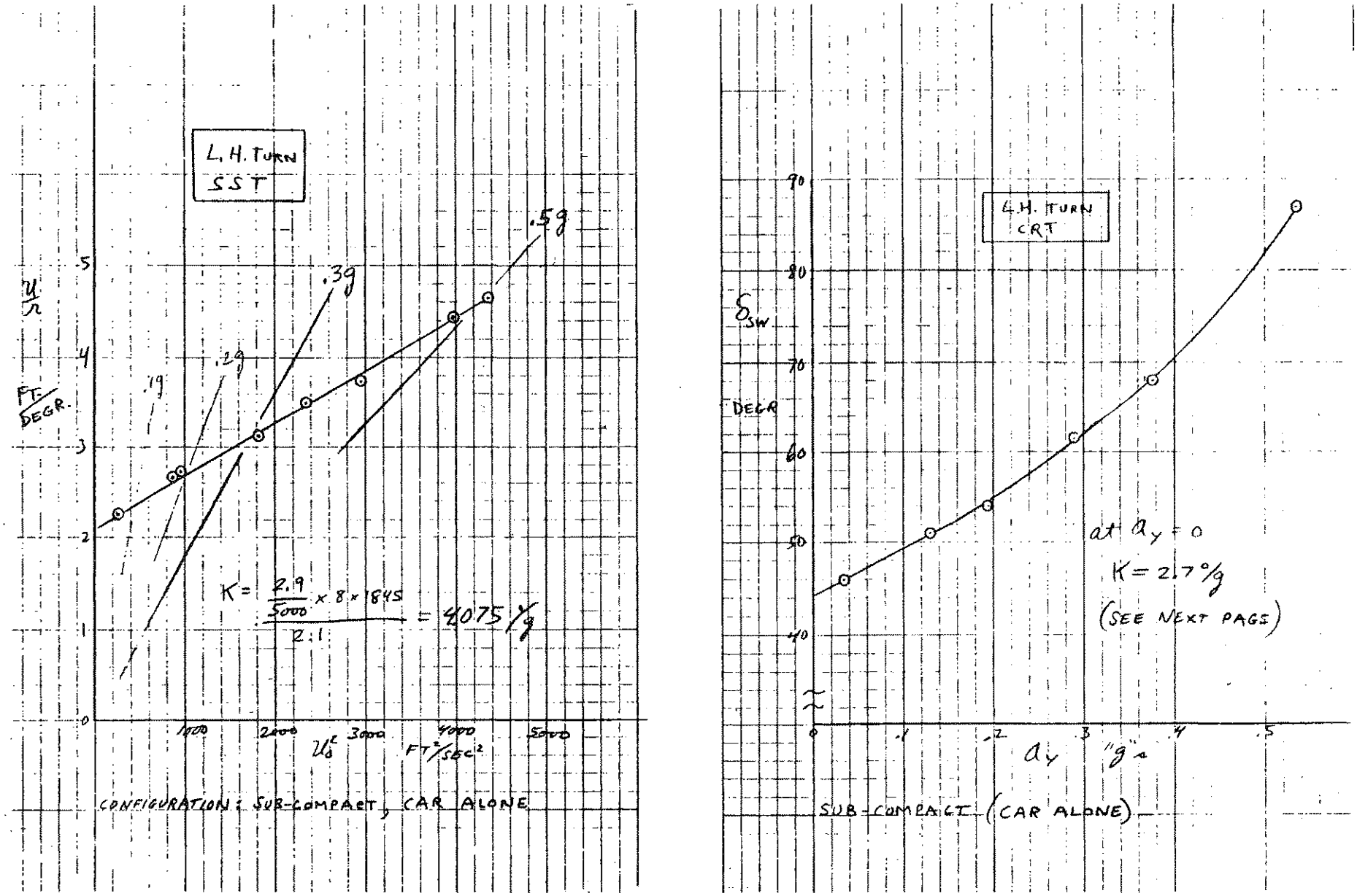
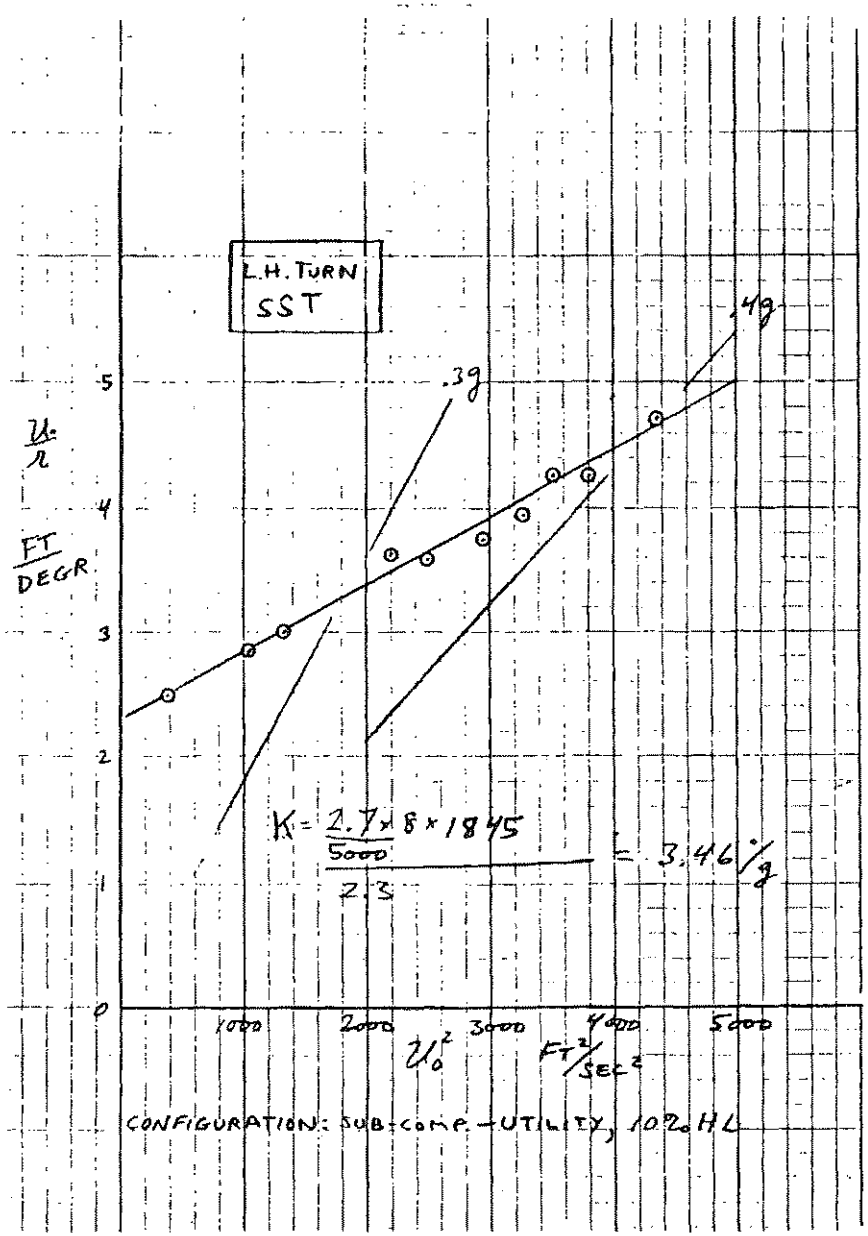
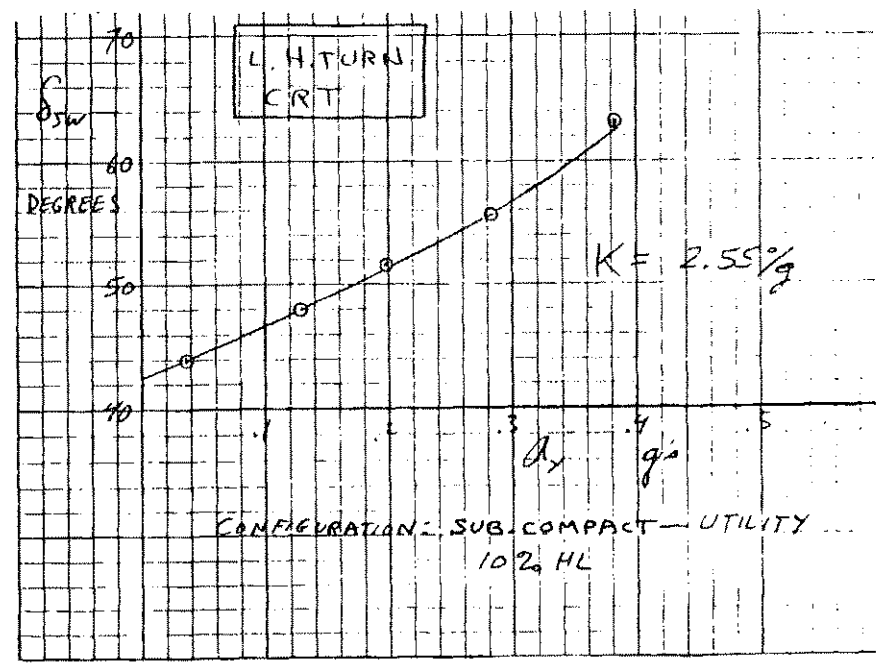


Figure F-3. Stability Factor Plots for Subcompact Tow Car and Combinations





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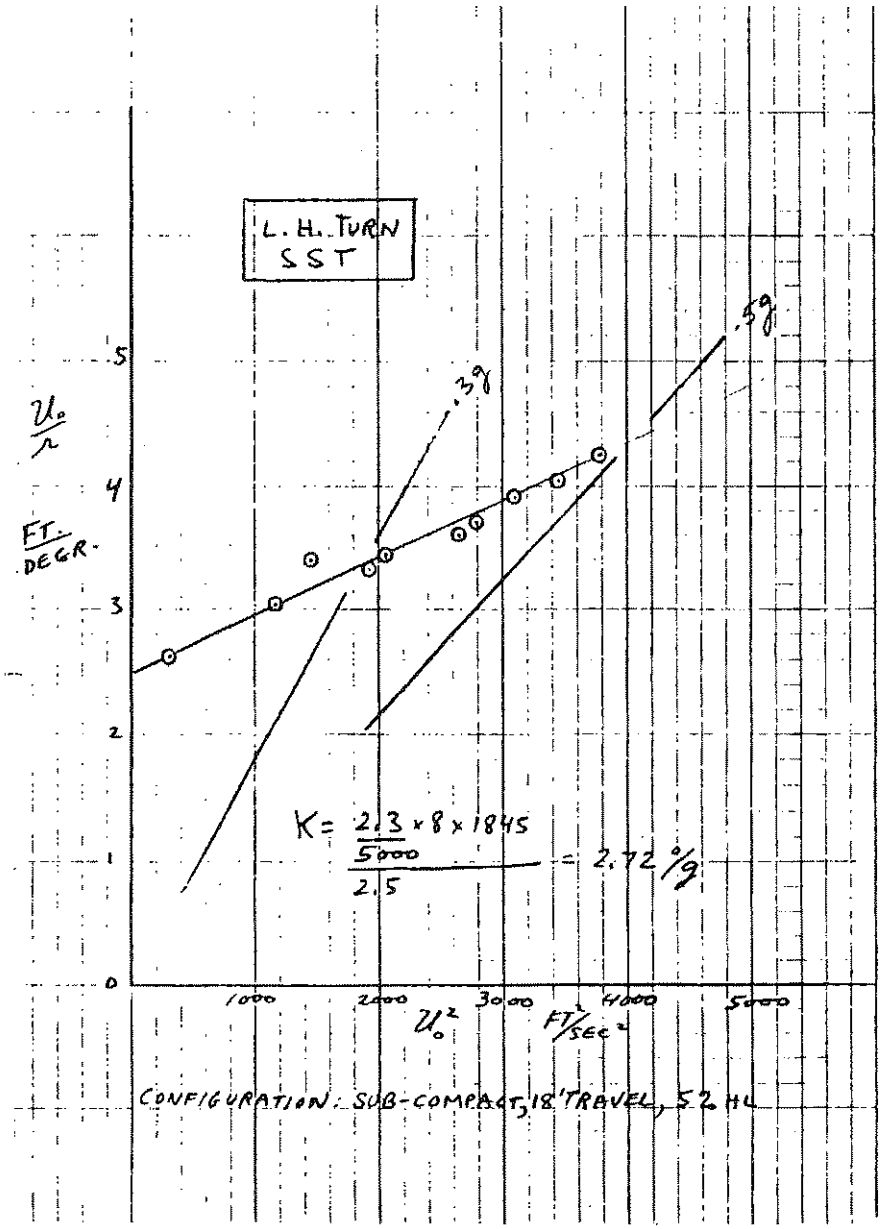

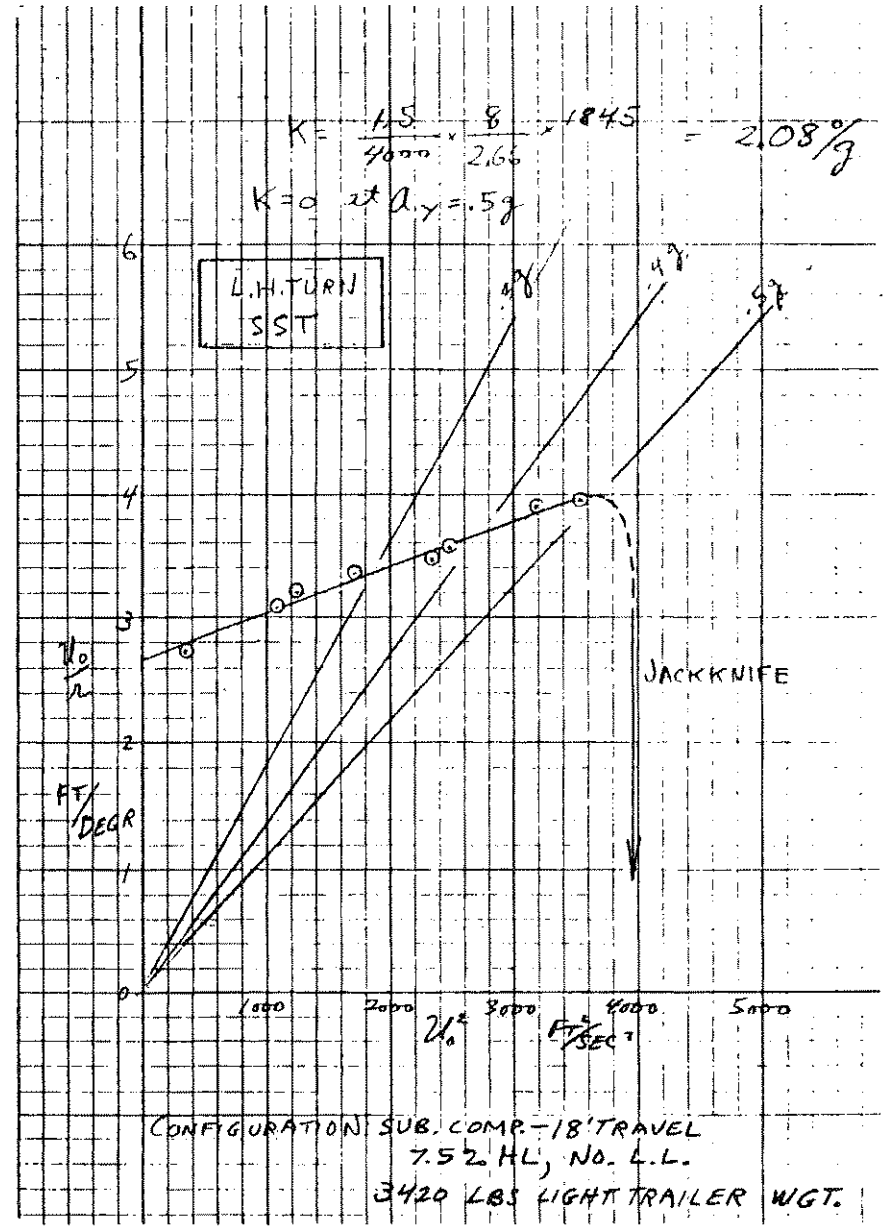

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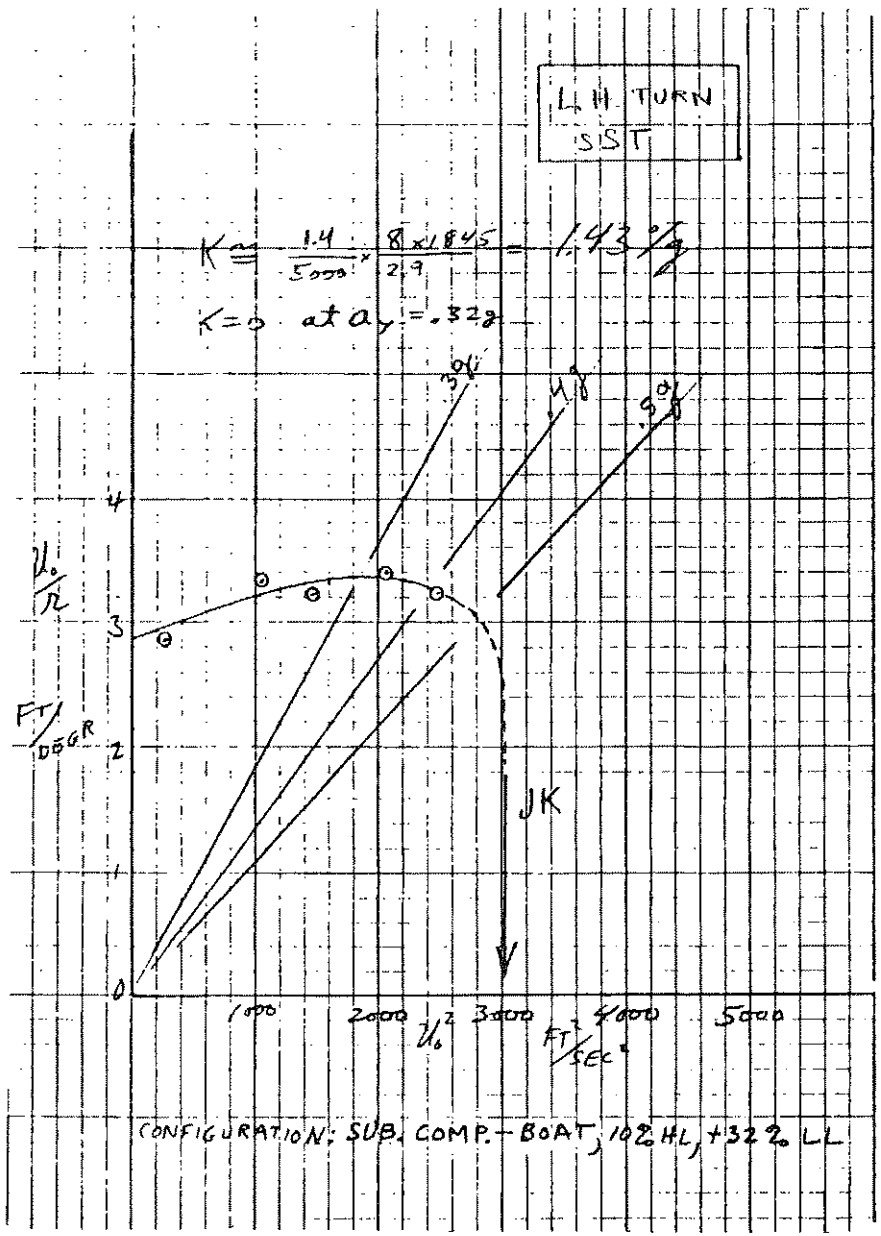

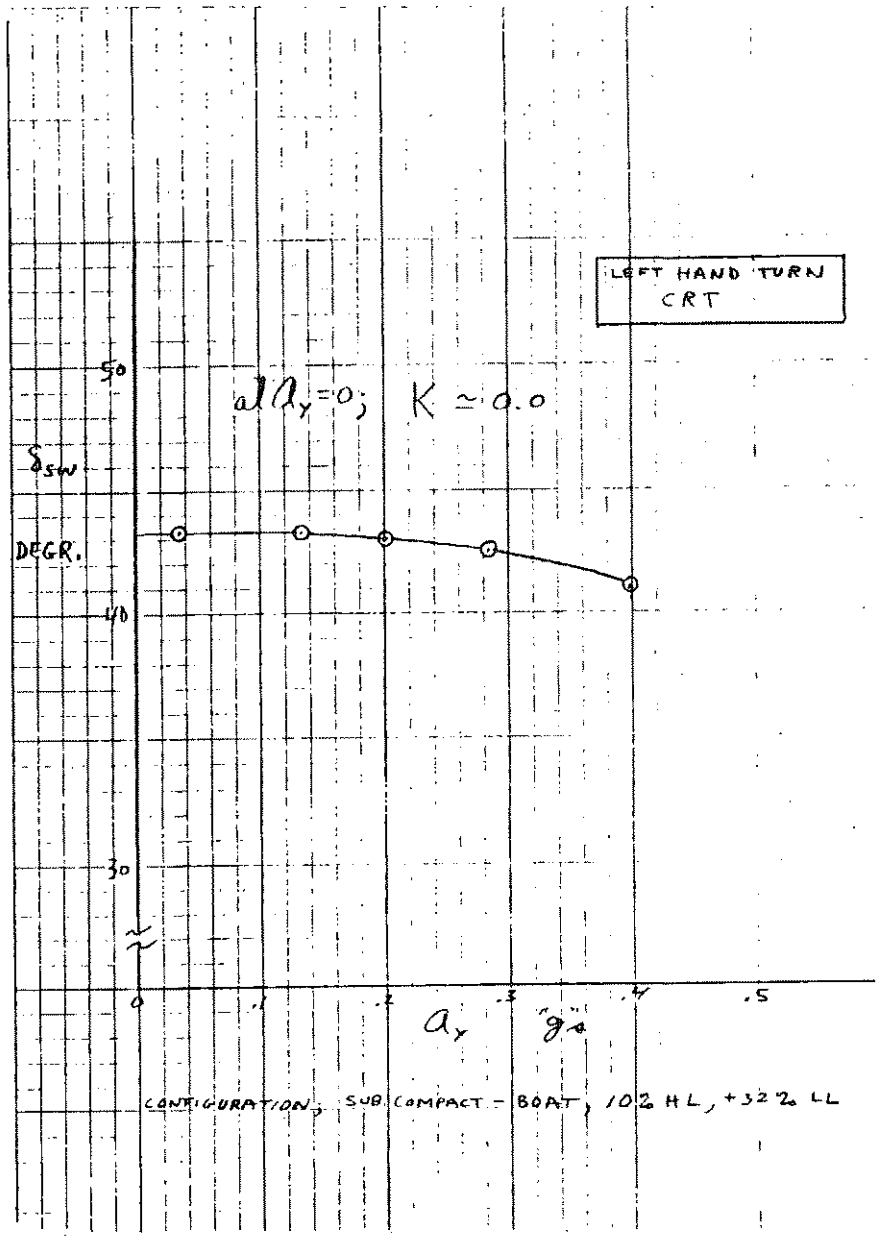

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