Track Train Dynamics

HIGH PERFORMANCE HIGH CUBE
COVERED HOPPER CAR PROGRAM,
HI CUBE 2000 PROTOTYPE DYNAMIC
PERFORMANCE TESTS, SUMMARY

REPORT NO. R-636

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HIGH PERFORMANCE HIGH CUBE COVERED HOPPER CAR PROGRAM, HI CUBE 2000 PROTOTYPE DYNAMIC PERFORMANCE TESTS, SUMMARY

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August, 1987

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13. ABSTRACT

As part of the co-operative Track-Train Dynamics High Performance, High Cube Covered Hopper Program, Transit America provided a prototype car - the HI CUBE 2000 for dynamic performance tests under the program's performance guidelines. This new design car was tested to evaluate its dynamic performance. This evaluation included operation in all significant dynamic performance regimes; namely, rock-and-roll, bounce, hunting, and curving. This report describes the test results in each of these performance regimes. Also, the selected test results for the HI CUBE 2000 are used to compare the dynamic performance with that of a base car - a 4750 cubic feet, 100 ton, conventional covered hopper car.

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EXECUTIVE SUMMARY

In 1980, the Track-Train Dynamics (TTD) Program issued "Performance Guidelines for High Performance/High Cube Covered Hopper Cars" to stimulate new car designs to improve upon the dynamic characteristics of existing covered hopper cars. The TTD Program organized a development effort to promote better designs and to subsequently evaluate the dynamic performance of these cars. Comparative performance characteristics of a "base" car with each prototype car submitted by car builders in accordance with the TTD Program, are determined by comprehensive tests and analytical studies.

Transit America, Budd Division, conceptualized and developed a systems approach to design a car intended for hauling grain and other commodities. Using analytical models and past experience, the dynamic performance was optimized and this culminated in a design called the HI CUBE 2000. The HI CUBE 2000 is a two-unit, three-truck, articulated car having a lowered center of gravity. It uses conventional three-piece trucks with constant contact side bearings to optimize dynamic performance under the full spectrum of railroad operating conditions. The car has a cubic capacity of 6250 cubic ft.

This report briefly describes the test program for the HI CUBE 2000 and summarizes the dynamic performance evaluation of

this prototype high-cube (6250 cubic feet) covered hopper car (Figure I), in comparison with the "Base" car (Figure II). All of dynamic performance tests were conducted at the Transportation Test Center, Pueblo, Colorado (Figure III).

Briefly, the roll angles and wheel unloading under rock and roll conditions were vastly reduced, as compared with the base car. This was true on tangent track as well as on curve (7-1/2 degree) track. The bounce performance tests showed lower maximum accelerations with less than 15% maximum wheel unloading (LD 6 value) as a "worst" condition. The car was operated up to 70 mph, with no clear carbody or wheelset hunting, while the "base car" exhibited flange-to-flange hunting at 60 mph under comparable conditions. Model predictions and the curving test data for the end and articulated trucks indicate that the curving performance is comparable with the base car. Spiral curve entry clearly showed an improved performance as compared with the base car.

The HI CUBE 2000 prototype operated successfully throughout the Dynamic Performance Test Program and the test results show that many of the program performance goals were achieved.

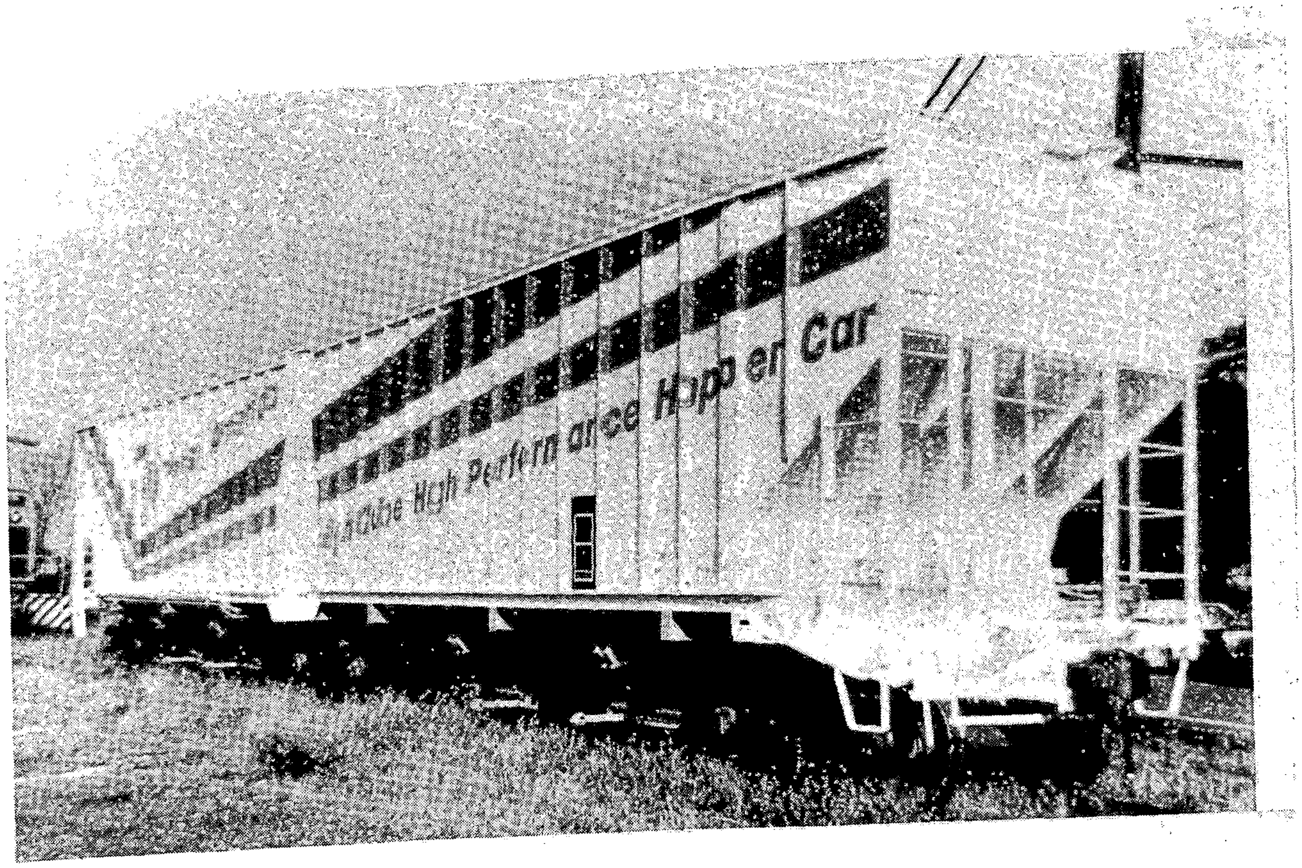

Figure I. HI CUBE 2000 Prototype Car (6250 cubic feet)

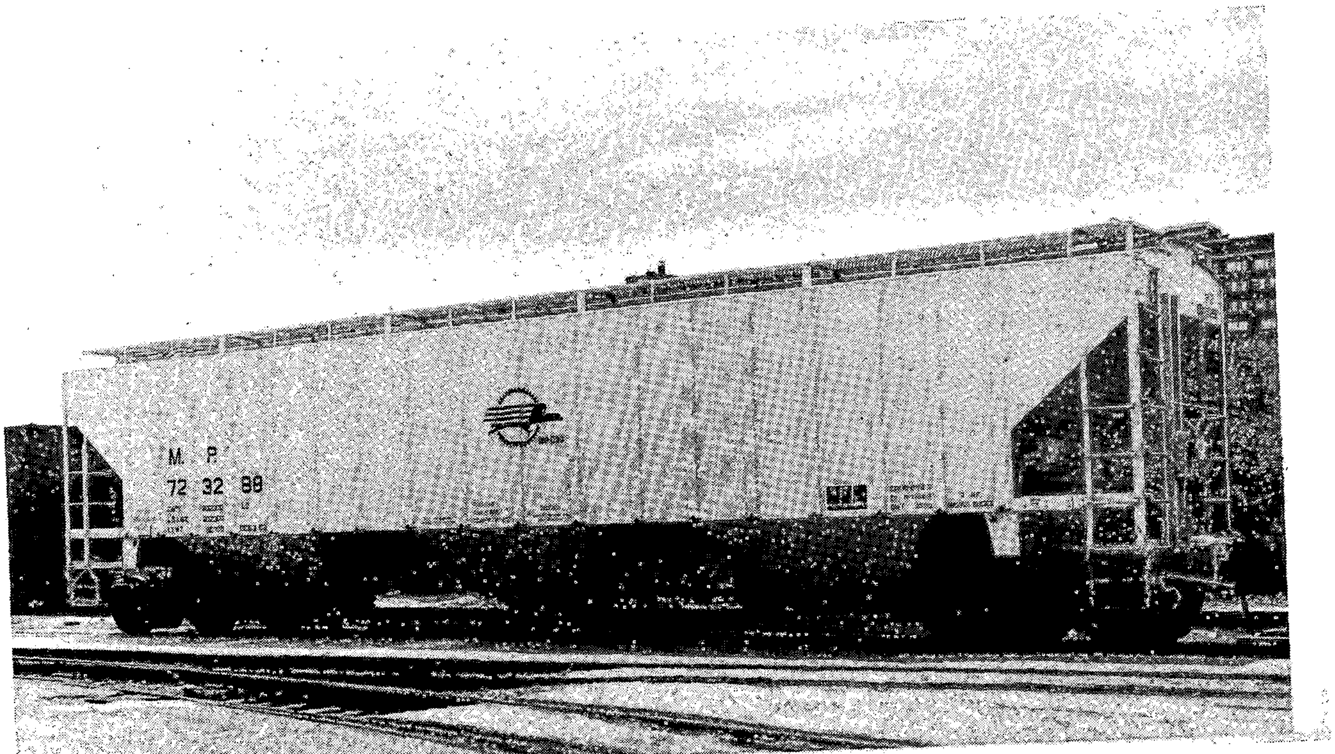

Figure II. Base Car - 4750 ft.^{3} 100-Ton Covered Hopper Car

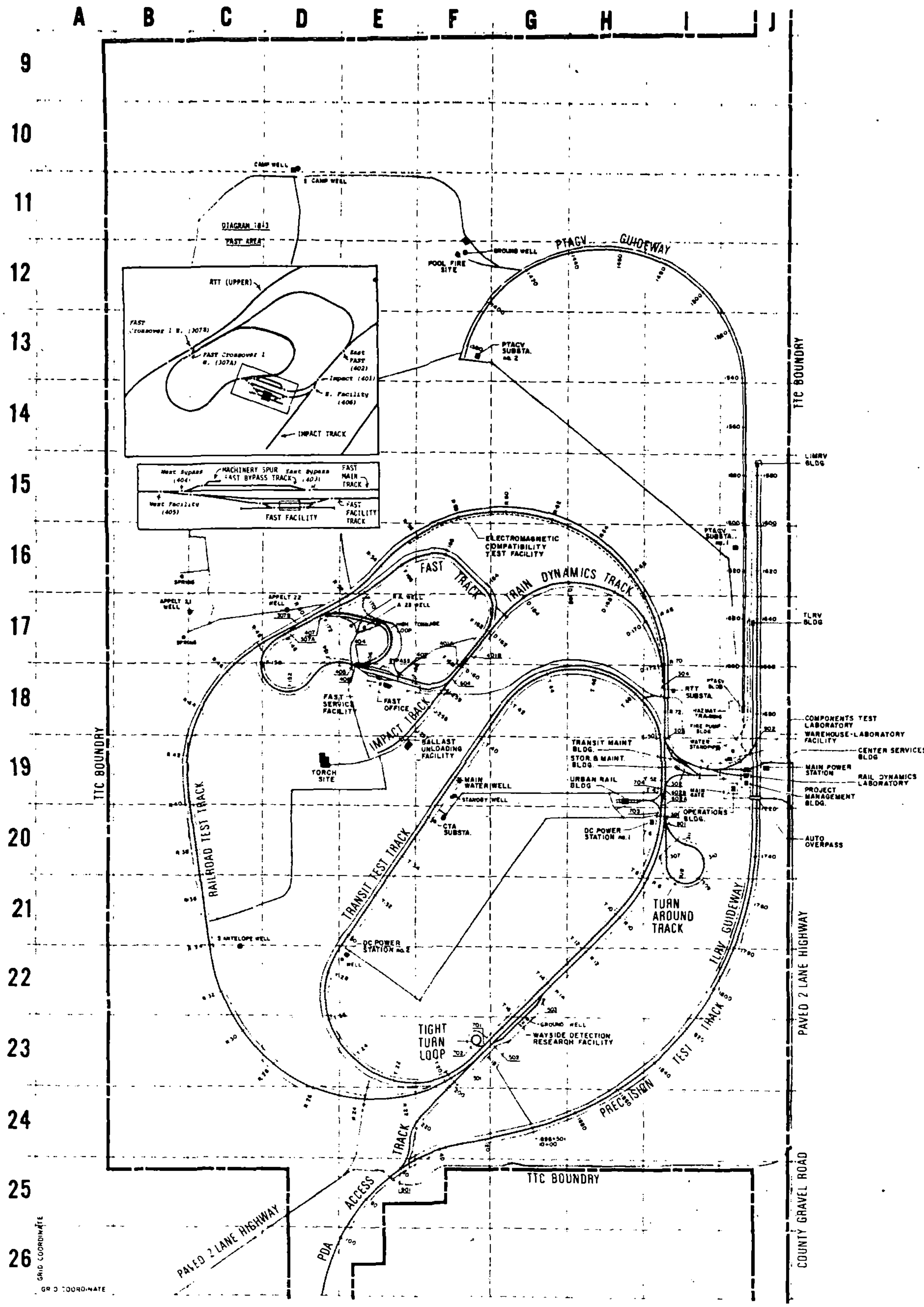

Figure III. Test Tracks at the Transportation Test Center, Pueblo, Colorado.

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The authors gratefully acknowledge and appreciate the involvement of the Federal Railroad Administration in the program, through both funding of the major portion of the test activities, and the support and encouragement by various personnel, in particular Mr. A. Bowers.

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In addition, the authors would like to thank all those AAR personnel who were involved in the planning, testing and data reduction activities. The efforts of the test crew, and particularly Messrs. Ron Bidwell, Mike Sherer, Jim Rzonca, Frank Hirsch and Judy Stadler, are appreciated.

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1.0 INTRODUCTION

In 1980, the Track Train Dynamics (TTD) Program issued Performance Guidelines (1) for High Performance/High Cube Covered Cars, 100 tons or greater, to stimulate new car designs and improve upon the dynamic characteristics of existing covered hopper cars. According to the guidelines, the new high-cube covered hopper car must be capable of safely carrying 100 tons or more of lading under all track conditions permitted in the current Federal Railroad Administration (FRA) Track Safety Standards. It must operate safely at the maximum speed permitted for freight equipment in each class of track up to a maximum of 80 mph, and must be capable of providing improved stability and trackability over all classes of track.

TTD subsequently organized a program for testing of a current design (base line case) covered hopper car, against which each new prototype car would be compared. This was followed by the actual testing of the base car. This was followed by the testing of two prototype cars, the THETA 80, which was supplied by the Thrall Car Manufacturing Company and the HI CUBE 2000, provided by Transit America. The base car was obtained on loan from the Union Pacific System (Missouri Pacific Railroad) for use in the test program. The HI CUBE 2000 prototype was offered for test in accordance with the project plans.

This report briefly describes the HI CUBE 2000 test program and summarizes the dynamic performance evaluation of this prototype car against the base car. The test program was funded by the Federal Railroad Administration and the Association of American Railroads. A series of reports [4,5,6] describing the base car dynamic performance serve as the base for comparing the performance of the HI CUBE 2000.

2.0 DESCRIPTION OF HI CUBE 2000 PROTOTYPE CAR AND THE BASE CAR

The Transit America HI CUBE 2000 was developed in response to the Track Train Dynamics Program's Performance Guidelines for High Cube Covered Hopper Cars. One prototype car was built for use in performance testing in accordance with the program requirements. This prototype car of the HI CUBE 2000 design is a two-unit car of articulated design. Three standard roller bearing trucks, with D-5 springs, are used. The end trucks are of 70-ton nominal capacity and are of the "Ride Control" type. The center or shared truck is a 100-ton capacity three-piece truck (Ride Control). Thirty-three inch diameter wheels are used on the end trucks while the center truck utilizes thirty-six inch diameter wheels. The gross rail load on the center truck is 131,500 lbs. while the 'A' and 'B' end trucks carry 98,000 and 100,000 lbs. respectively. New Miner constant-contact side bearings are used on all trucks.

The total car cubic capacity is 6250 cubic feet. Each unit has two compartments having 24 in. x 42 in. gravity outlet gates. The body is a flat-sided, externally-braced structure. Twenty-inch trough hatches are used.

The total length between coupler pulling faces is 72' 3". The car meets AAR Plate 'B' clearances and has a maximum height of 15' 1" over hatch covers. AAR strength and curve negotiability requirements are met.

The car has a through full (unit) length center sill. An ASF articulated connector (125-ton nominal rated capacity) is used to connect units and to support the center-side of each unit on the shared truck.

A single brake control valve is used for the two unit car and only the 'B' end unit has a handbrake.

M-901-E Standard Draft Gears and a conventional Type E coupler (SBE-60) is utilized.

The estimated center-of-gravity height, of the HI CUBE 2000 when loaded to cubic and gross load is ninety (90) inches above top of rail.

The base car is a 100-ton covered hopper car with a capacity of 4750 cubic feet. The car was equipped with conventional three-piece trucks, with constant-column friction damping, using conventional double roller side bearings. The estimated center of gravity heights are 95 inches loaded and 61 inches empty above the top of rail. This particular design represents a very large part of the existing fleet in service.

3.0 TEST PROGRAM SUMMARY

The test program was designed around the available track sites at the Transportation Test Center (TTC), at Pueblo, Colorado. The tests were conducted to evaluate the dynamic performance of the car in rock-and-roll, pitch-and-bounce, hunting, curving, and curve entry/exit regimes. Tests were conducted for both empty and loaded conditions, except for hunting (empty only). Curving tests were run for the empty and loaded car. However, the emphasis was on the loaded case. The curves ranged from 50 minutes to 7.5 degrees on the RTT, FAST, TDT and Balloon loop tracks. Curve entry/exit was a part of the curving tests on the FAST loop. A test matrix is listed in Table 3.1.

The test consist included, in order, a four-axle locomotive, the AAR-100 Research Car, the base car (used both as a buffer car and to collect additional data to check the repeatability of the previously completed base car tests), the HI CUBE 2000 prototype car, and another car. The data were collected using angle-of-attack probes, accelerometers, displacement transducers and roll gyros. The lateral and vertical wheel loads were measured using an IITRI design of instrumented CN (Radford) profiled wheelsets [2]. Automatic Location Detectors (ALD) were used to identify the beginning and end of each test section. A summary of instrumentation is listed in Table 3-2. Additional details of the same basic instrumentation can be found in the base car detailed reports (4, 5, 6) describing the rock and roll, bounce, hunting and curving performance.

Table 3.1 Test Matrix - HI CUBE 2000 Car Dynamic Performance Tests.

SERIES & TRACK	APPROX. NO. OF RUNS	PERFORMANCE REGIME	LOAD OR EMPTY	HIGH CUBE CAR CONFIGURATION WHEELSET PROFILES, CONICITY "B" END 70 TON TRUCK		"A" END 70 TON TRUCK	COMMON 100 TON TRUCK	SPEEDS		DIRECTION, ETC.
A RTT	10	HUNTING	E	AAR 1:20	+	AAR 1:20	+ 1:20	35 mph & UP	= 5 mph	CCW
C RTT	10	HUNTING	E	CN RADFORD	+	CN RAD.*	+ CN RAD. *	35 mph & UP	= 5 mph	CCW
D FAST	10	CURVING	L	CN RADFORD	+	CN RAD.*	+ CN RAD. *	10, 20, 30, 35, 40, 45 mph		CW, CCW
E RTT	10	CURVING	L	CN RADFORD	+	CN RAD.*	+ CN RAD. *	30, 40, 50, 60, 70 mph		CW, CCW
F TDT	10	CURVING	L	CN RADFORD	+	CN RAD.*	+ CN RAD. *	30, 40, 50, 55, 60 mph		CW, CCW
G BALLOON	10	CURVING	L	CN RADFORD	+	CN RAD.*	+ CN RAD. *	15, 20 (25 cw),30, 35, 40 mph		CW, CCW
H BALLOON	10	CURVING	E	CN RADFORD	+	CN RAD.*	+ CN RAD. *	15, 20 (25 cw),30, 35, 40 mph		CW, CCW
I RTT	10	CURVING	E	CN RADFORD	+	CN RAD.*	+ CN RAD. *	30, 40, 50, 60, 70 mph		CW, CCW
J BALLON	10	BUNCHED SPIRAL	E	CN RADFORD	+	CN RAD.*	+ CN RAD. *	15, 20 (25 cw),30, 35, 40 mph		CW, CCW
K FAST	10	CURVING	L	AAR 1:20	+	AAR 1:20	+ 1:20	10, 20, 30, 35, 40, 45 mph		CW, CCW
L RTT	10	CURVING	L	AAR 1:20	+	AAR 1:20	+ 1:20	30, 40, 50, 60, 70 mph		CW, CCW
M TDT	10	CURVING	L	AAR 1:20	+	AAR 1:20	+ 1:20	30, 40, 50, 55, 60 mph		CW, CCW
N BALLOON	10	CURVING	L	AAR 1:20	+	AAR 1:20	+ 1:20	15, 20 (25 cw),30, 35, 40 mph		CW, CCW
O BALLOON	10	CURVING	E	AAR 1:20	+	AAR 1:20	+ 1:20	15, 20 (25 cw),30, 35, 40 mph		CW, CCW
P LIM	10	ROCK & ROLL	L	CN RADFORD	+	CN RAD.*	+ CN RAD. *	12 mph & UP	= 1 mph	3/4" Amp. Only
Q LIM	10	ROCK & ROLL	E	CN RADFORD	+	CN RAD.*	+ CN RAD. *	20 mph & UP	= 5 mph = 1 mph	3/4" Amp. Only
R LIM	10	BOUNCE	L	CN RADFORD	+	CN RAD.*	+ CN RAD. *	20 mph & UP	= 1 mph	3/4" Amp. Only
S LIM	10	BOUNCE	E	CN RADFORD	+	CN RAD.*	+ CN RAD. *	20 mph & UP	= 5 mph	3/4" Amp. Only
T BALLOON	10	CURVE ROCK & ROLL	L	CN RADFORD	+	CN RAD.*	+ CN RAD. *	12 mph & UP	= 1 mph	One Direction, 3/4 in.
U BALLOON	10	CURVE ROCK & ROLL	E	CN RADFORD	+	CN RAD.*	+ CN RAD. *	20 mph & UP	= 5 mph = 1 mph	One Direction, 3/4 in.
V	10 10	IMPACT- TANGENT	E	CN RADFORD	+	CN RAD.*	+ CN RAD. *	5 mph & UP	= 0.5 mph	IMPACT A END IMPACT B END

* DENOTES INSTRUMENTED WHEEL SET:
FOR THE LEADING AXLE ONLY OF TRUCK AT THE "A" END,
BOTH AXLES FOR ARTICULATED TRUCK

Table 3.2 Summary of Instrumentation for HI CUBE 2000 for Dynamic Performance Tests

Meas. #	TYPE	Location/Direction	Rock & Roll	Bounce	Curving & Curve Entry	Hunting	Dynamic Squeeze
HI CUBE 2000 Car							
1	ALD Event	A End of Test Vehical	x	x	x	x	
2	Speed	AAR-100 SPEED	x	x	x	x	
3-8	Angle of Attack*	Axles 6, 4, and 3	x		x	x	
9-26	Vertical Wheel Loads Laterial Wheel Loads L/V Ratios	Axles 6, 4, and 3	x	x	x	x	
27-32	Spring Displacement	All Spring Groups	x	x			
33-40	Side Bearing Displacement	Each Side Bearing			x		
41-43	Gyro, Roll Angle Rate	A, CA, and B ends	x				
44-47	Acceleration @ Car cg (Lat.)	A, CA, CB, and B ends				x	
48-53	Accel. at Bearing Adapter (Lat.)	Axles 6, 4, 3, 2, and 1				x	
54-56	Vertical Accel. @ Center Plate	A, B, and C Trucks		x			
57	Dynamometer Coupler	A and B ends					x
Base Car							
58-59	Spring Displacement	All Spring Groups	x	x			
60-63	Side Bearing Displacement	Each Side Bearing			x		
64	Gyro, Roll Angle Rate	A end	x				
65	Acceleration @ Car cg (Lat.)	A end				x	
66-67	Accel. at Bearing Adapter (Lat.)	Axles 4, and 2				x	
68-69	Vertical Accel. @ Center Plate	A and B Trucks		x			

* Typically, angle-of-attack, for each wheelset, is computed as follows:

$$\frac{D_3 - D_4}{\text{(distance between tranducers)}},$$

where D_3, D_4 are the lateral displacements for the leading and trailing transducers.

4.0 ROCK-AND-ROLL PERFORMANCE

To evaluate the rock-and-roll dynamic performance of the prototype car, the peak-to-peak carbody roll angles versus speed and wheel loads were compared with those of the base car [4]. Three different criteria were selected to compare the maximum vertical wheel loads and wheel unloading: L95, and the L5 and minimum values. The L95 value is defined as the level which is exceeded 5% of the time in the test section. The L5 value is defined as the level which is exceeded 95% of the time. Also, the LDS 6 value, a level below which the time trace is continuous over 6 feet of track, is also used. A minimum value is also shown for each speed.

For the tangent rock-and-roll tests, a tangent section of the LIM track at TTC was shimmed to create a 0.75 inch peak-to-peak nominal crosslevel variation for twenty rail lengths. A similar shimming pattern, for ten rail lengths, was used on the Balloon Loop, a 7.5 degree curve with 4.5 inches of superelevation, for the curve rock-and-roll evaluation.

4.1 Tangent Track Rock-and-Roll

Figures 4.1 through 4.6 show comparisons of the tangent track rock-and-roll performance of the two cars. The peak-to-peak carbody roll angles for the base car reached 10.6 degrees at 15.8 mph for the loaded and 8.9 degrees at 24.8 mph for the empty cases, respectively. For the HI CUBE 2000, they were 5.2 degrees at 14.5 mph for the loaded, and 6.3 degrees (B end unit) at 23 mph for the

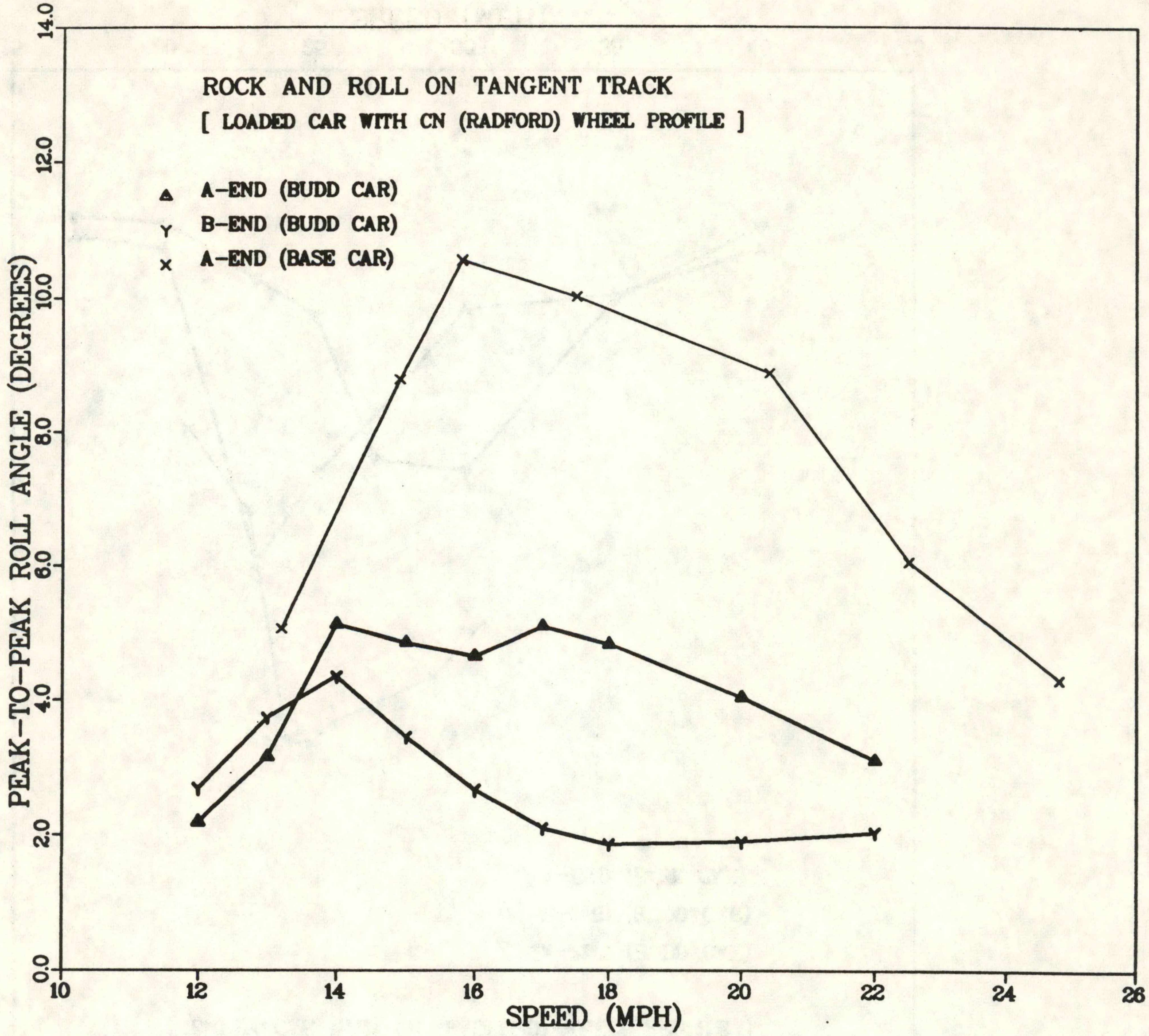


Figure 4.1: HI CUBE 2000 and Base Car Peak-to-Peak Roll Angles <u>versus</u> Speed, Loaded on Tangent Track.

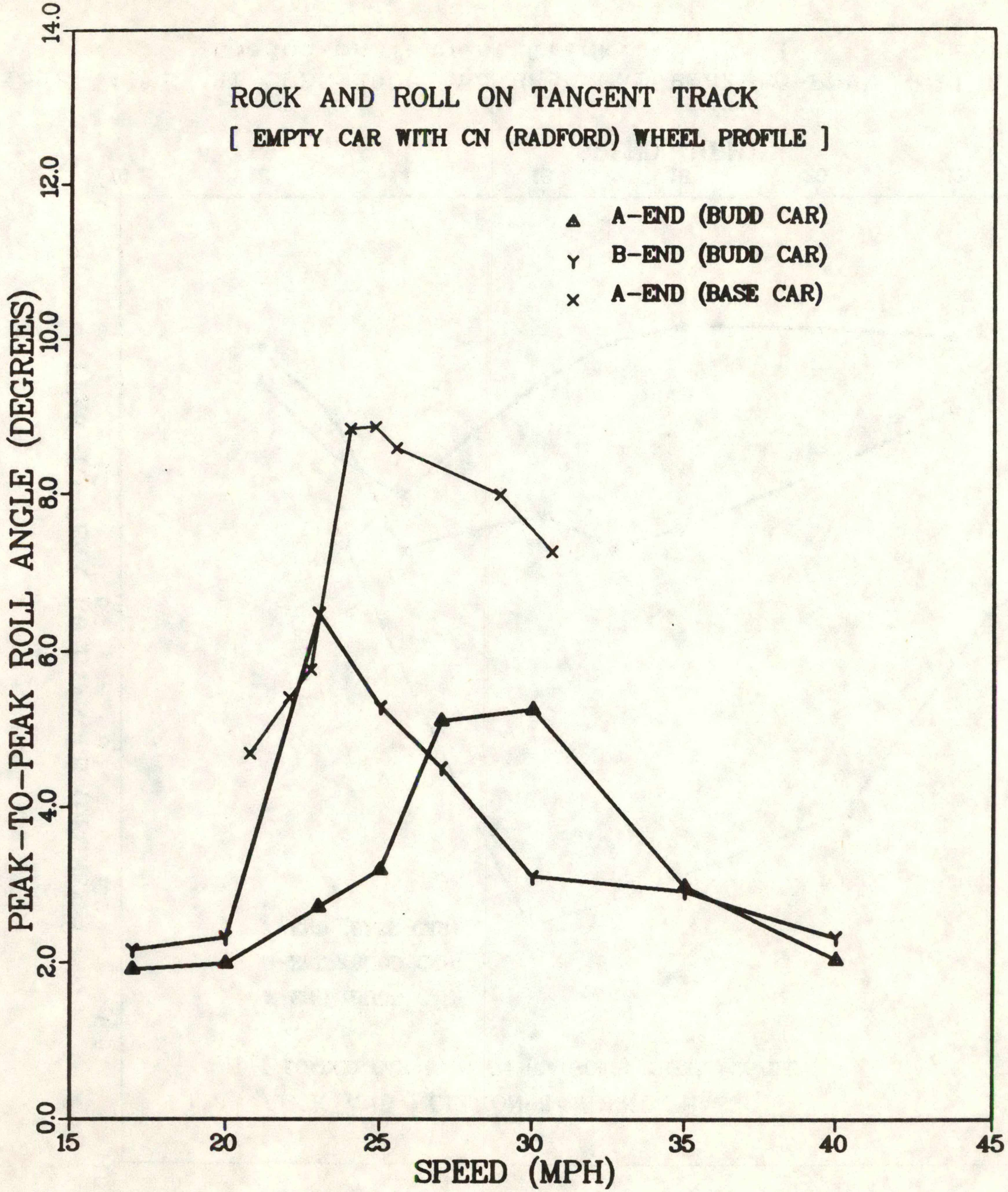


Figure 4.2: HI CUBE 2000 and Base Car Peak-to-Peak Roll Angles <u>versus</u> Speed, Empty on Tangent Track

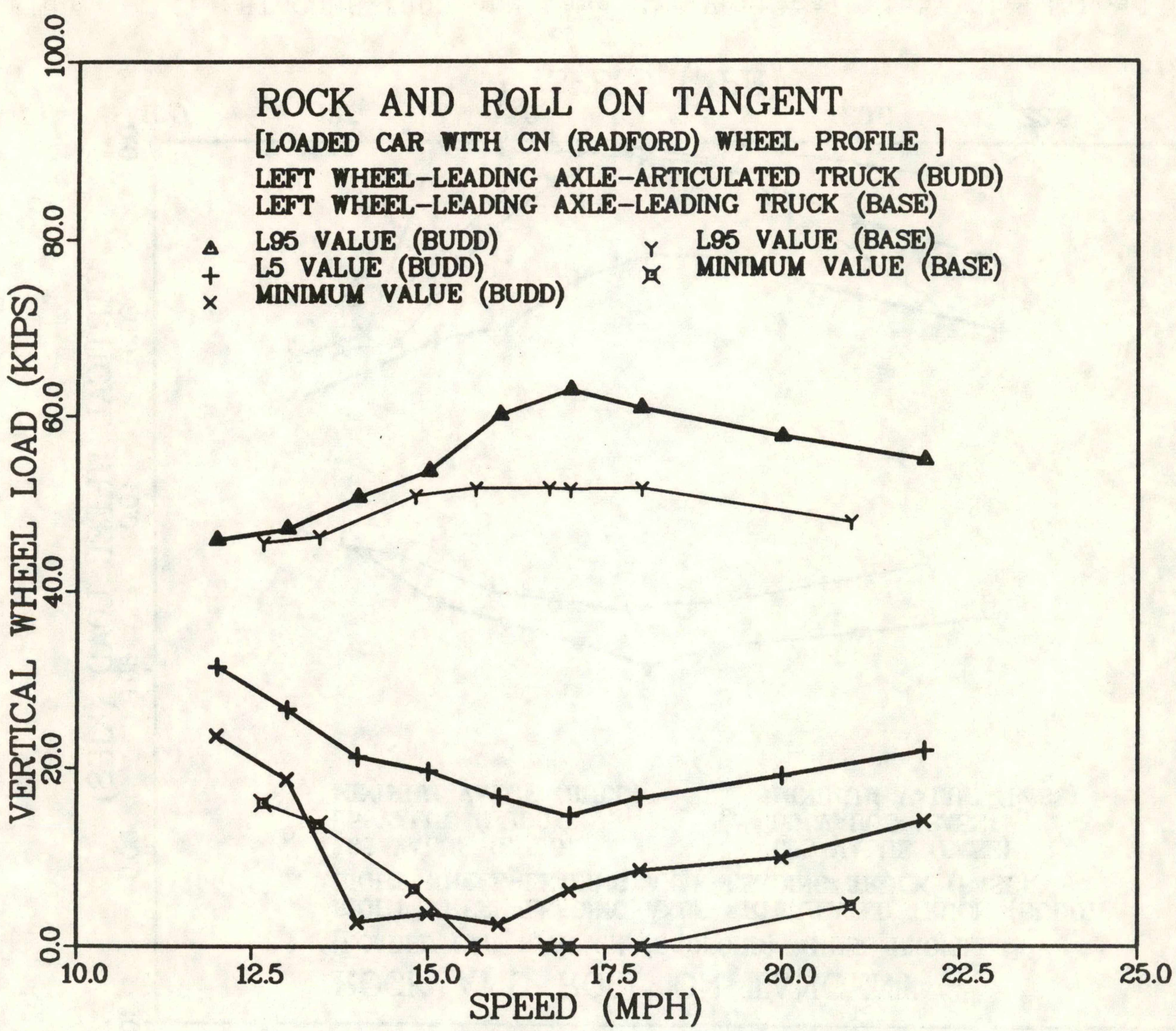


Figure 4.3: HI CUBE 2000 and Base Car Vertical Left Wheel Load <u>versus</u> Speed, Loaded on Tangent Track.

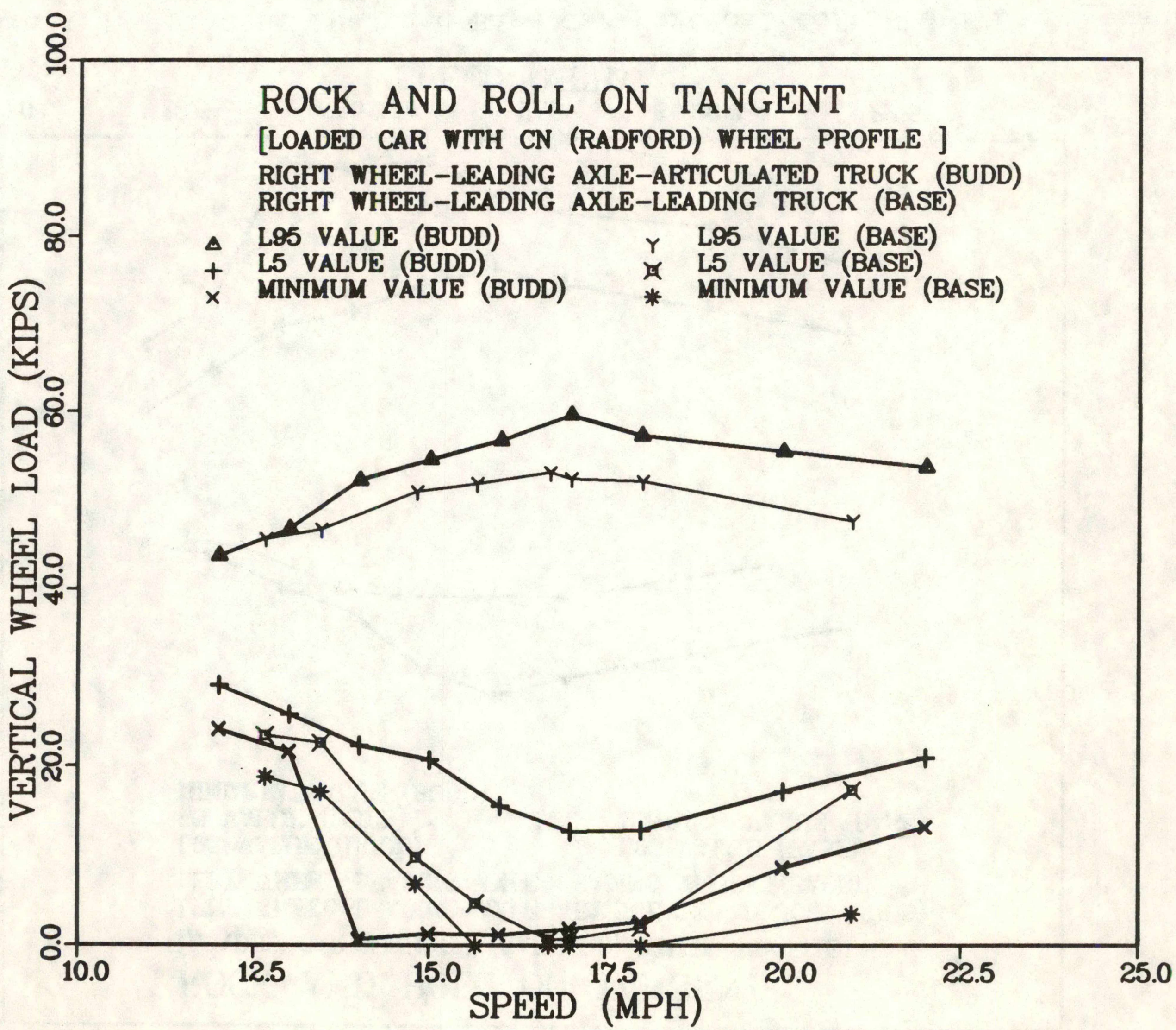


Figure 4.4: HI CUBE 2000 and Base Car Vertical Right Wheel Load <u>versus</u> Speed, Loaded on Tangent Track.

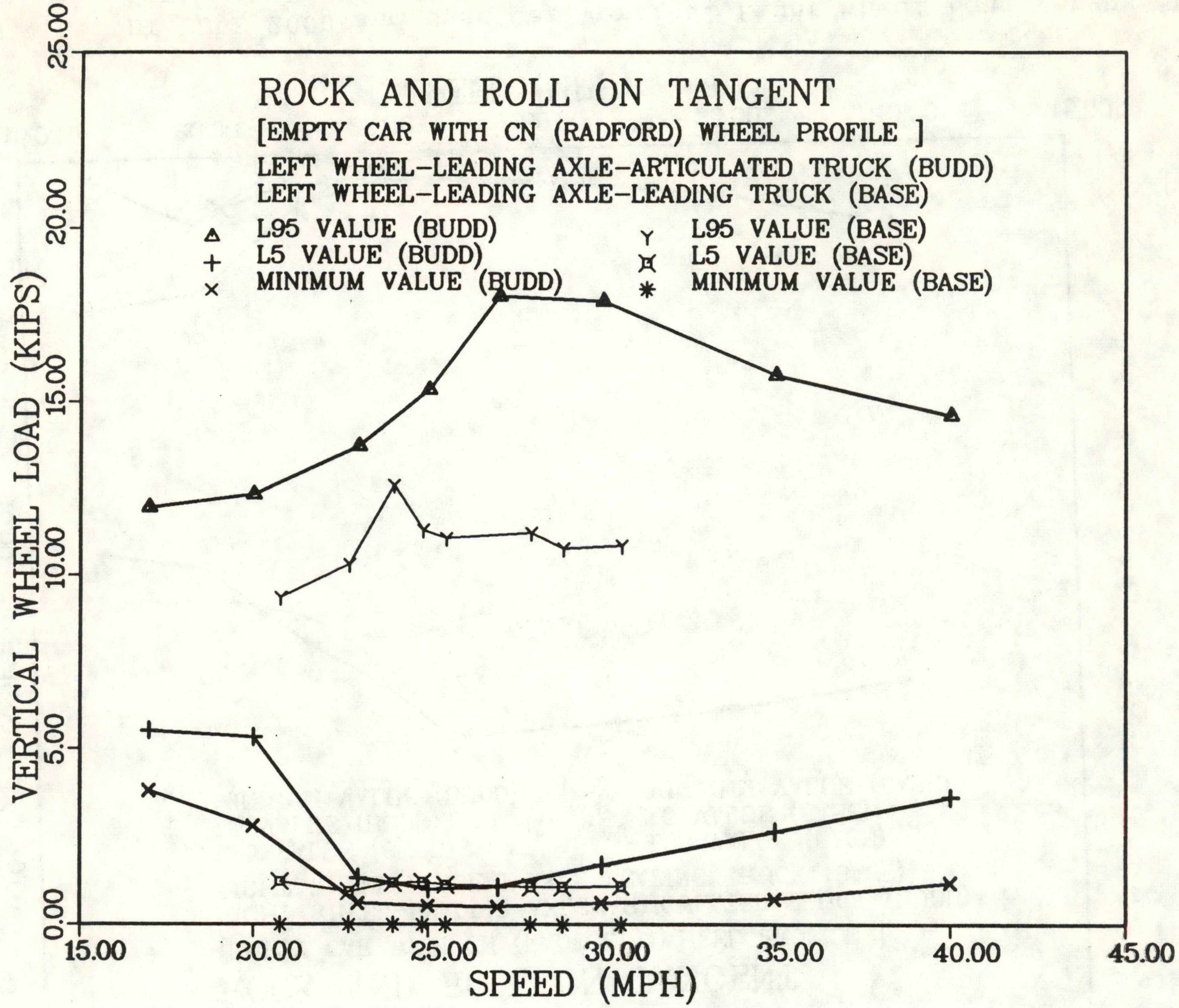


Figure 4.5: HI CUBE 2000 and Base Car Vertical Left Wheel Load <u>versus</u> Speed, Empty on Tangent Track.

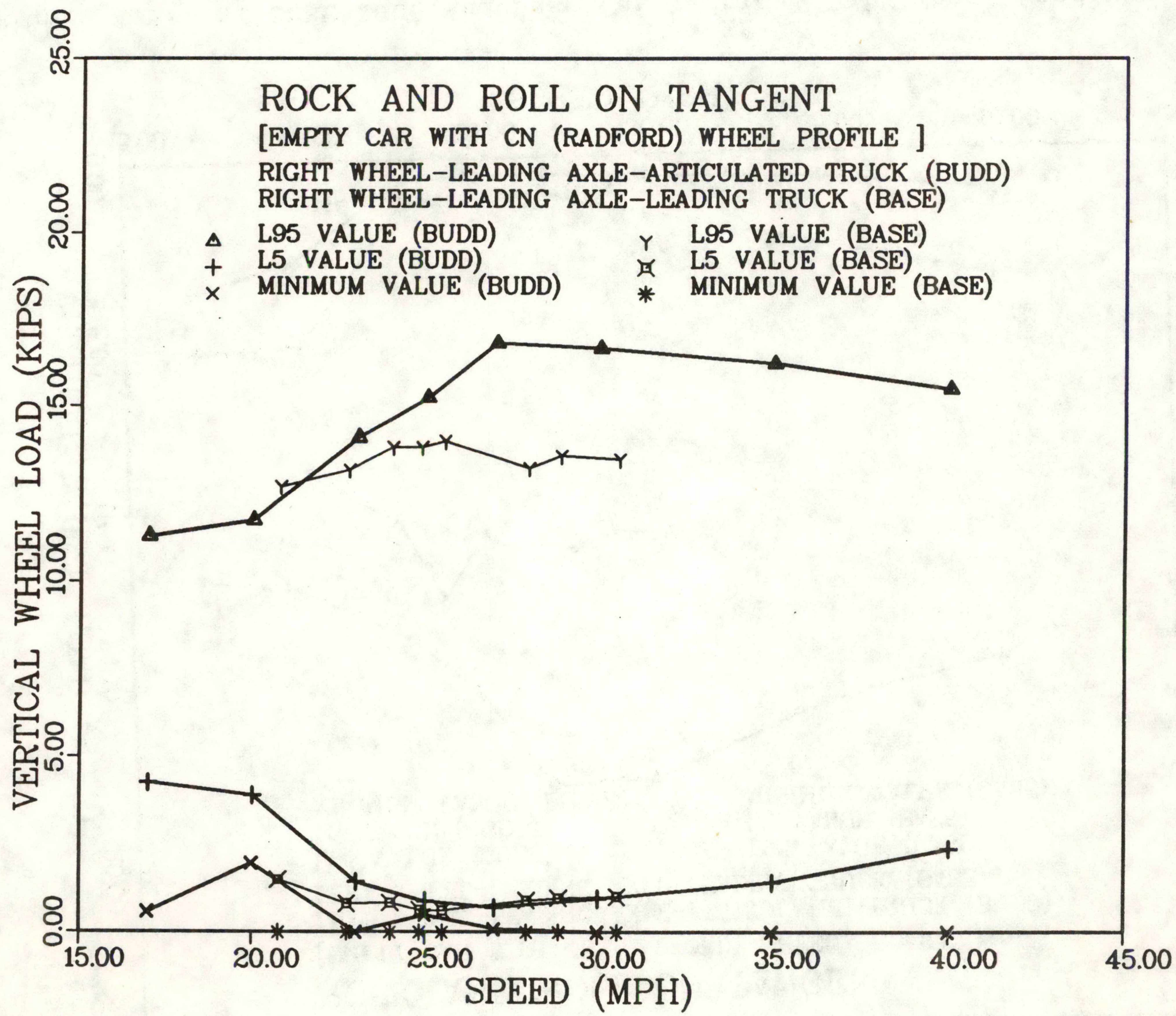


Figure 4.6: HI CUBE 2000 and Base Car Vertical Right Wheel Load <u>versus</u> Speed, Empty on Tangent Track.

empty cases, respectively. These roll angles were the maximum attained in any of the runs. There is some difference in the speed at which the two units of the articulated car attain maximum roll response. The 'A' end unit response was somewhat lower than the 'B' end.

In comparing wheel loads only the articulated truck of the HI CUBE 2000, which has the equivalent load of a 100-ton truck, with 36-inch diameter wheels is considered. The end trucks have 33-inch diameter wheels with less than 70-ton equivalent loads.

The leading axle vertical wheel load measurements (left and right wheels) for the base car showed considerable wheel unloading including some wheel lifts at both sides of the leading axle. The HI CUBE 2000 however, did not experience any wheel lifts for either loading case.

For a clear comparison of the loaded car wheel unloading it is best to compare the L5 values for both cars. In Figure 4.4 one can clearly see that the HI CUBE 2000, has much less unloading than the base car as seen by comparing the L5 values. The corresponding values for the left wheel in Figure 4.3 are very similar, but unfortunately, the base car values are not available, due to an instrumentation problem.

As with the loaded car case, the empty car wheel unloading shows an improvement (considering L5 values) for the HI CUBE 2000 over the base car. (Figures 4.5 and 4.6)

4.2 Curved Track Rock-and Roll

Figures 4.7 through 4.12 show comparisons of the curved track rock-and-roll performance of the two cars. In this test regime, the maximum peak-to-peak carbody roll angles were reduced from 10.2 degrees at 18 mph to 3.8 degrees at 21 mph for the loaded car, and from 9.2 degrees at 24.3 mph to 4.8 degrees at 32 mph for the empty HI CUBE 2000. For the loaded case, the base car experienced more wheel unloading at the high rail (right wheel) than the HI CUBE 2000 over the speed range of interest, as evidenced by comparing, in Figure 4.10, the L5 values, although both cars had occasional complete unloading. In the case of the empty car wheel unloadings, again, the HI CUBE 2000 was better than the base car as seen in Figure 4-11. Also, the maximum vertical wheel loads for both cars were comparable.

In summary, the HI CUBE 2000 did reduce the carbody peak-to-peak roll angle and wheel unloading, without increasing the maximum wheel load levels, in both rock-and-roll test regimes. The improved performance of the HI CUBE 2000 prototype in the rock-and-roll regime can partly be attributed to the multi-unit nature of the carbody and the lowered carbody center of gravity height. This improvement should manifest itself as an improved safety record.

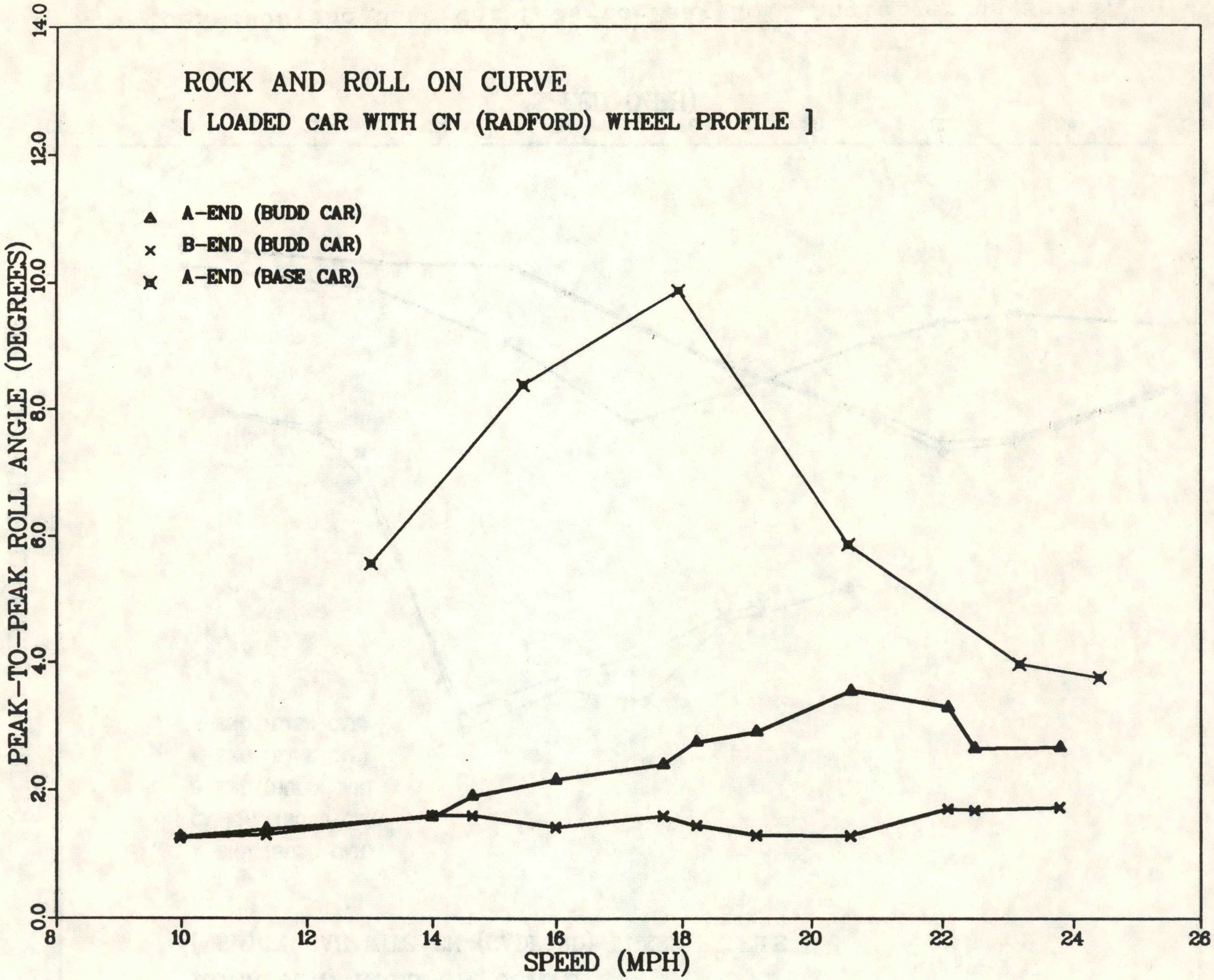


Figure 4.7: HI CUBE 2000 and Base Car Peak-to-Peak Roll Angle <u>versus</u> Speed, Loaded on 7-1/2-degree Curve.

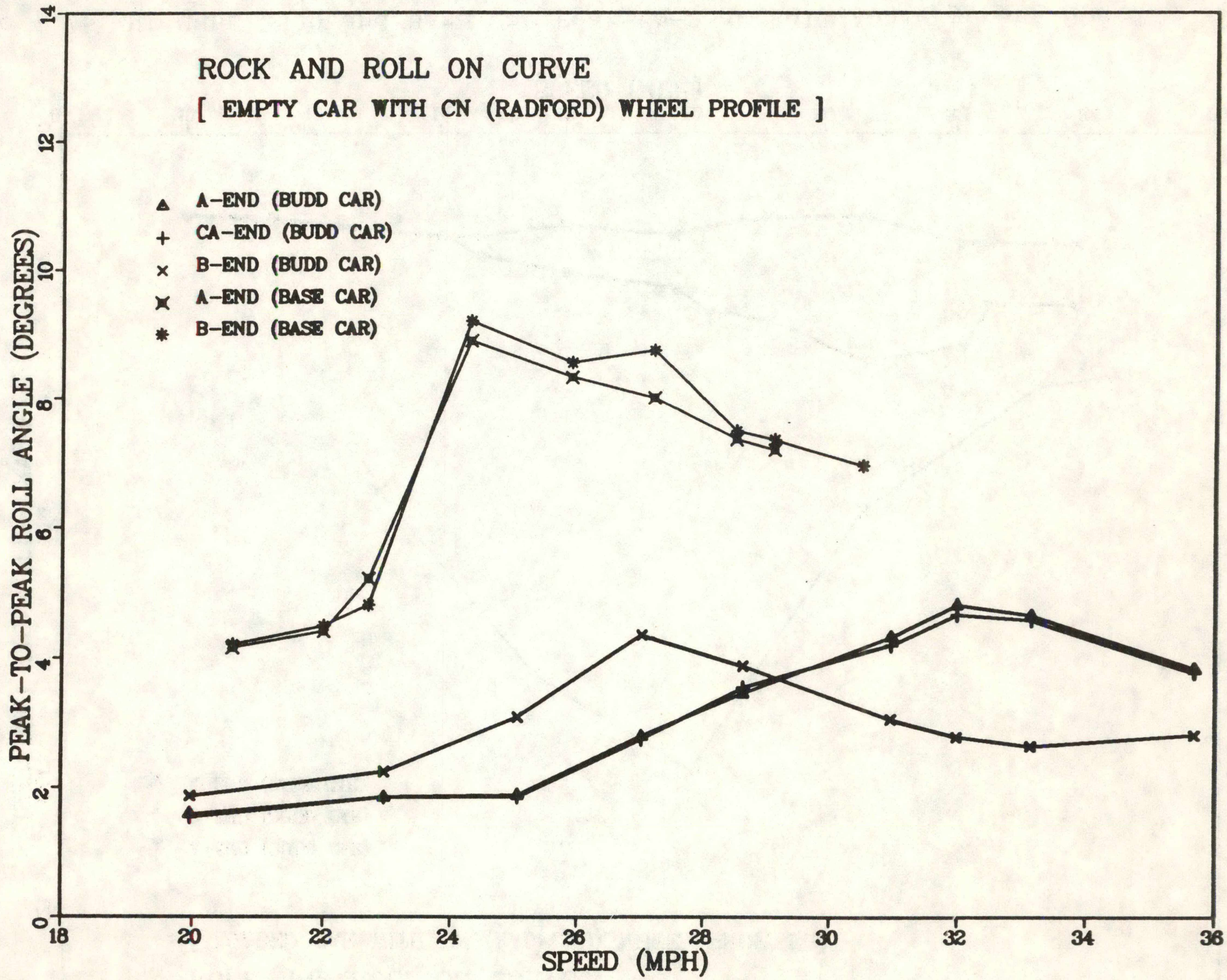


Figure 4.8: HI CUBE 2000 and Base Car Peak-to-Peak Roll Angle <u>versus</u> Speed, Empty on 7-1/2-degree Curve.

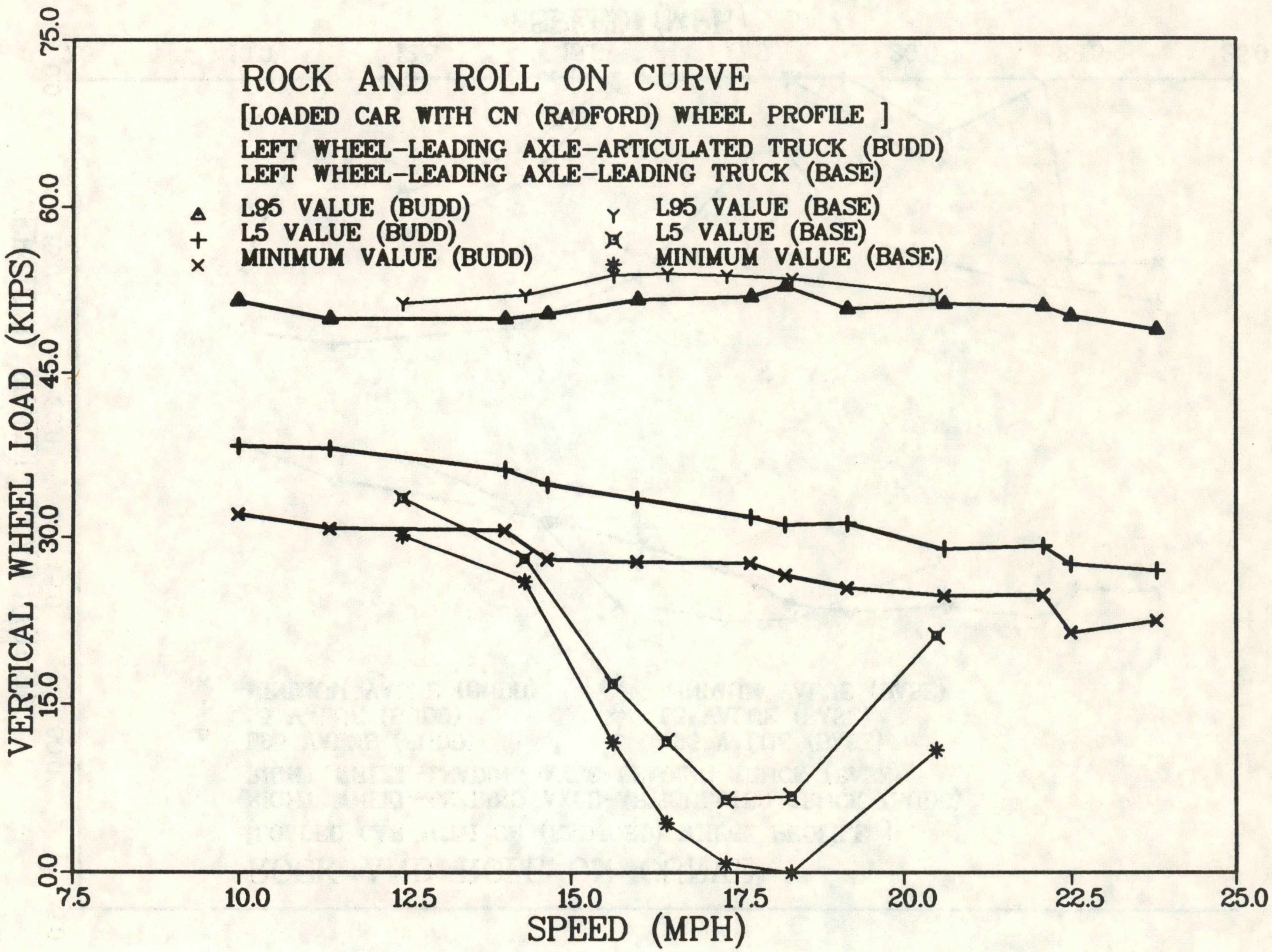


Figure 4.9: HI CUBE 2000 and Base Car Vertical Left Wheel Load versus Speed, Loaded on 7-1/2-degree Curve.

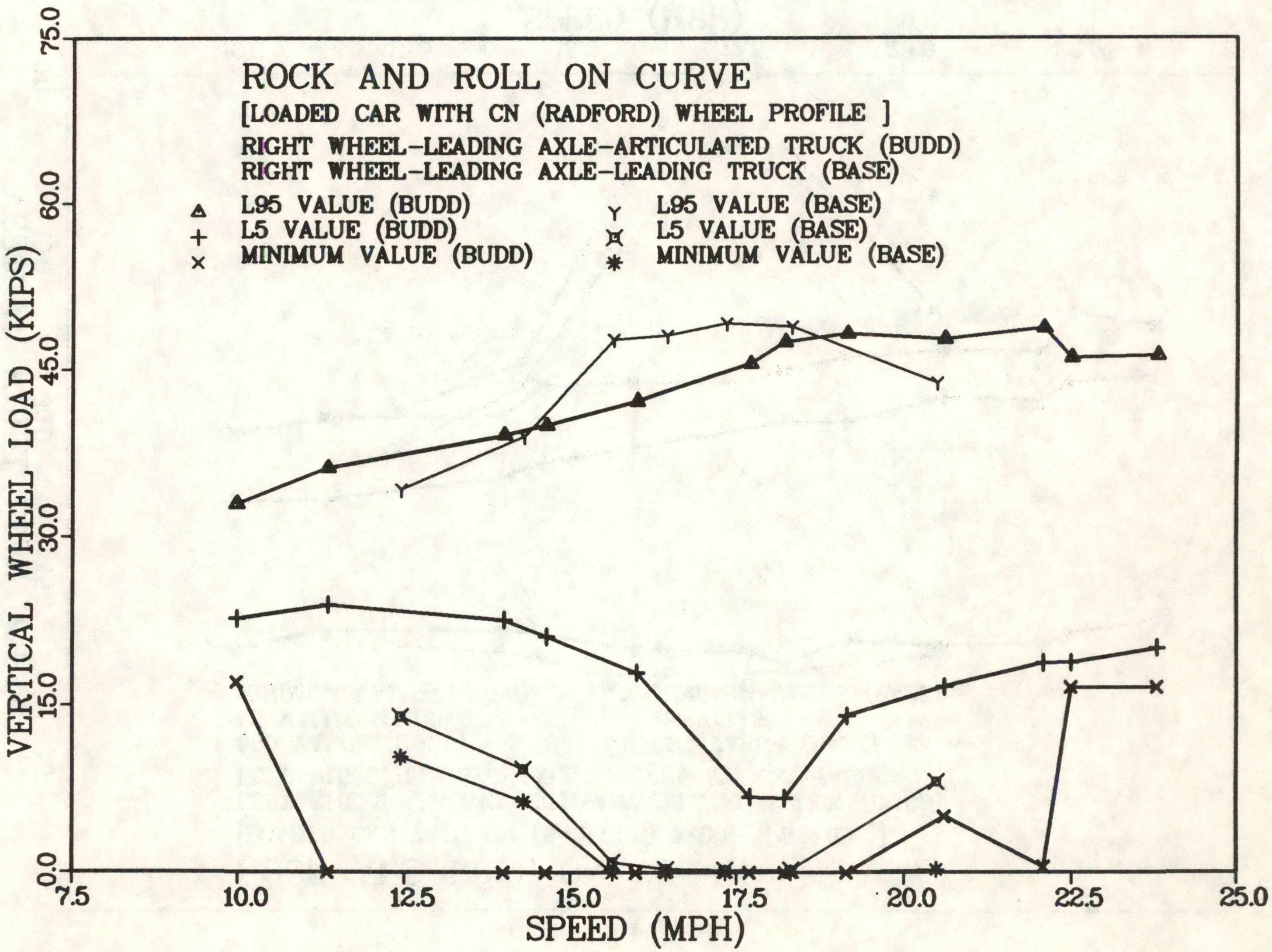


Figure 4.10: HI CUBE 2000 and Base Car Vertical Right Wheel Load versus Speed, Loaded on 7-1/2-degree Curve.

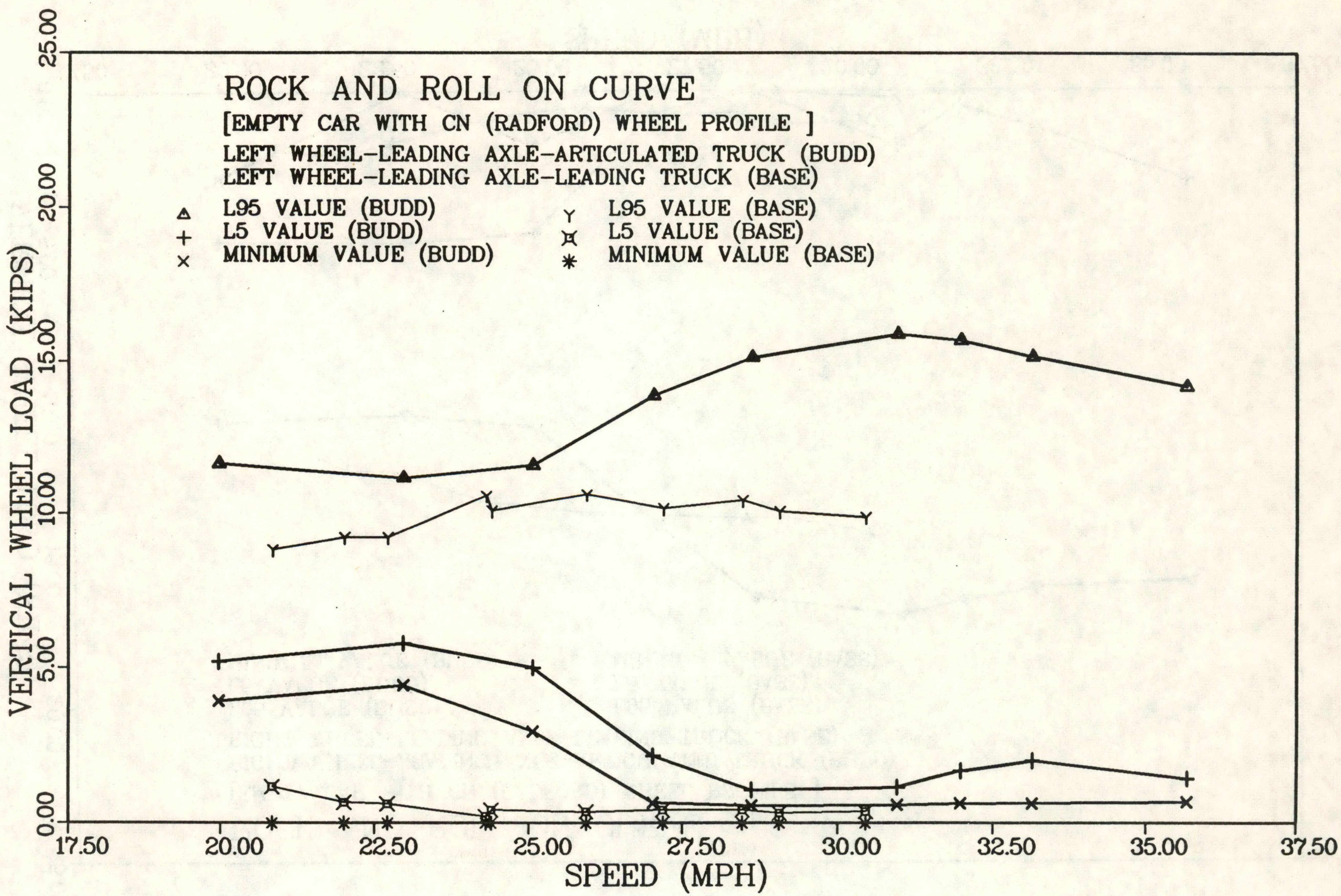


Figure 4.11: HI CUBE 2000 and Base Car Vertical Left Wheel Load <u>versus</u> Speed, Empty on 7-1/2-degree Curve.

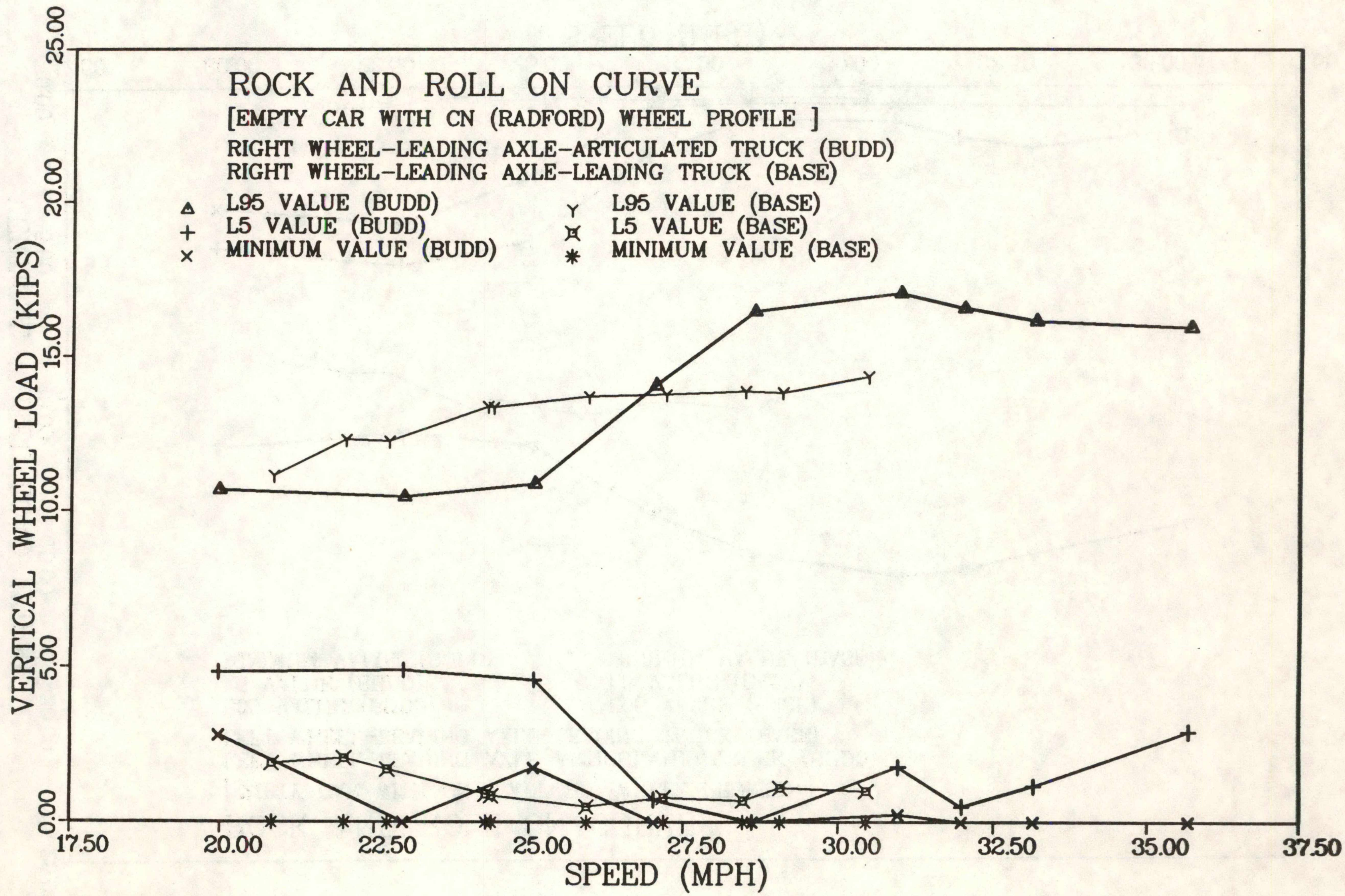


Figure 4.12: HI CUBE 2000 and Base Car, Vertical Right Wheel Load <u>versus</u> Speed, Empty on 7-1/2-degree Curve.

5.0 PITCH-AND-BOUNCE REGIME

The pitch-and-bounce tests were conducted on another section of the LIM test track, in which non-staggered (parallel-joint) track was used with a 0.75 inch amplitude shimming pattern.

The empty car pitch-and-bounce tests indicated no clear resonance of the two unit vehicle at speeds up to 70 mph, which is the speed limit for safely stopping at this particular test site.

The loaded car test results are shown here in Figures 5.1 thru 5.5. The root mean square (rms) bounce and pitch accelerations, in the frequency range of 0-20 Hz, (Figures 5.1 and 5.2), show a peak value for the base car at 56 mph, with a corresponding maximum wheel unloading of 54% (Figures 5.4 and 5.5). The wheel unloading for the HI CUBE 2000 is much lower as seen by comparing the LD6 values. The rms bounce accelerations do not show a clear peak (Figure 5.1). The rms pitch acceleration shows an increasing level up to 65 mph for the leading unit. Figures 5.4 and 5.5 indicate that the wheel loads did not change much, despite the increase in pitch acceleration. Figure 5.3 compares center plate RMS vertical accelerations for HI CUBE 2000 and the base car.

In summary, the HI CUBE 2000 performed better than the base car and exhibited lower acceleration levels and lower wheel unloadings over the range of test speeds.

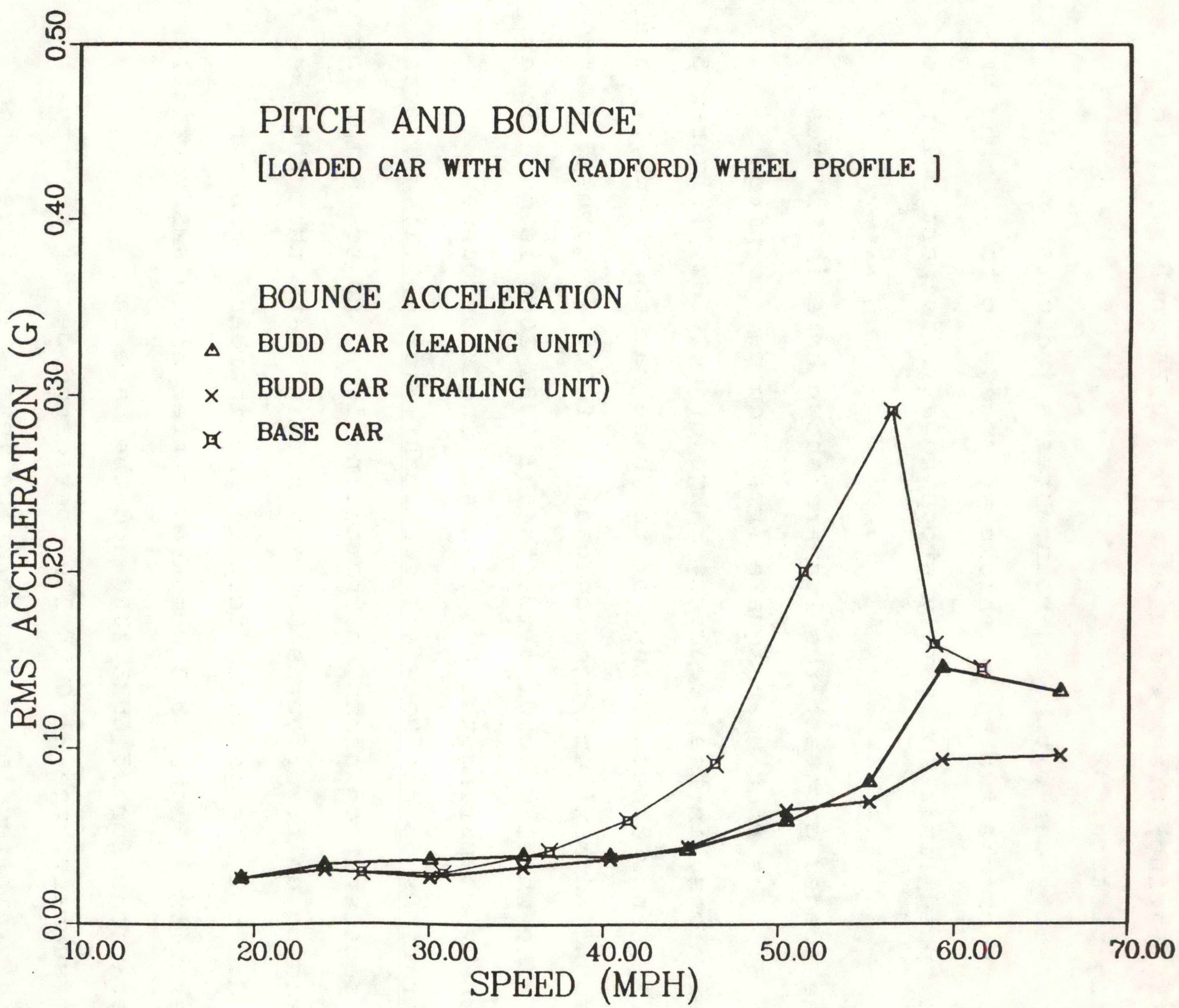


Figure 5.1: HI CUBE 2000 and Base Car RMS Bounce Acceleration versus Speed, Loaded Cars.

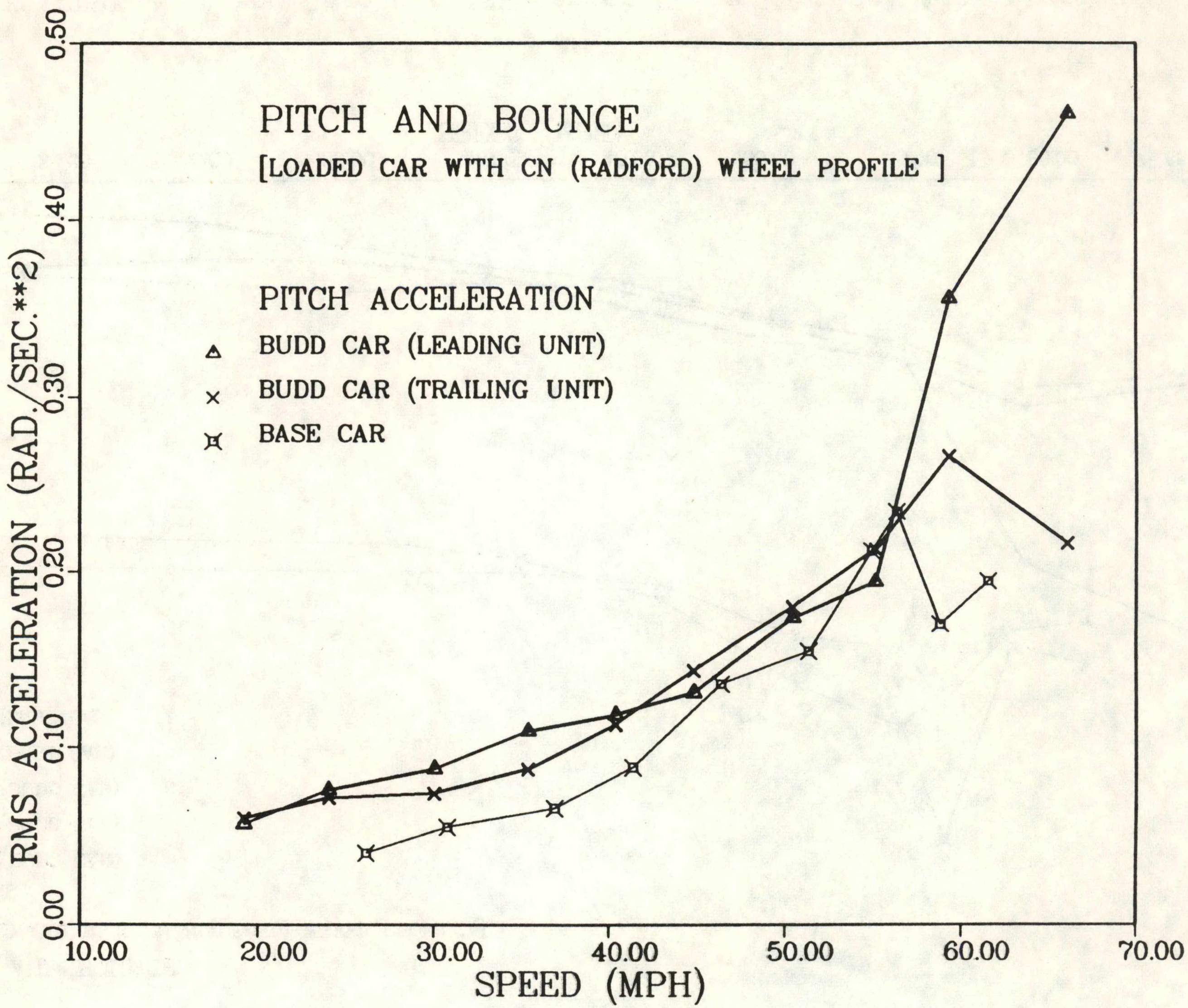


Figure 5.2: HI CUBE 2000 and Base Car RMS Pitch Acceleration <u>versus</u> Speed, Loaded Cars.

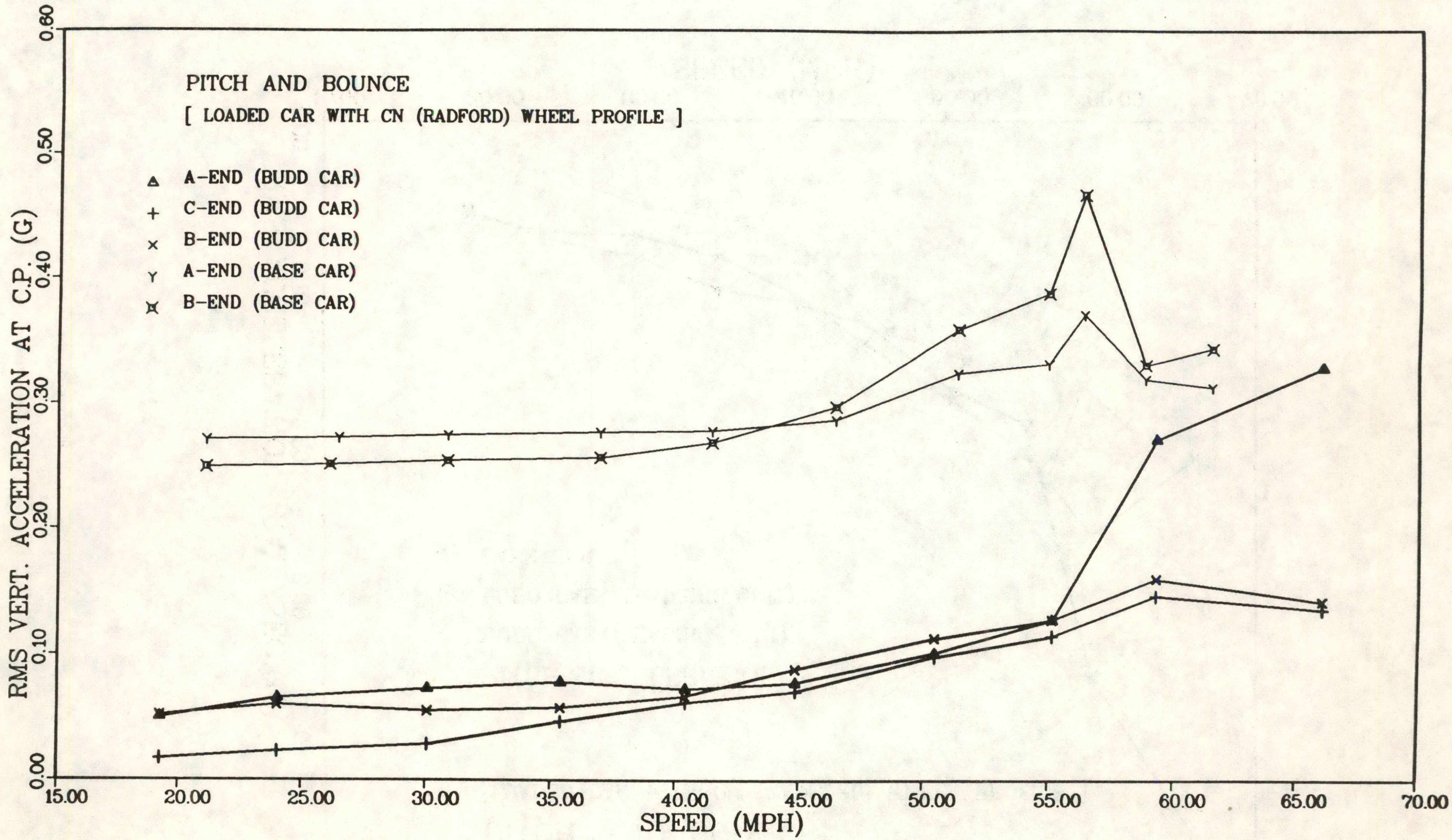


Figure 5.3: HI CUBE 2000 and Base Car RMS Center Plate Vertical Acceleration versus Speed, Loaded Cars.

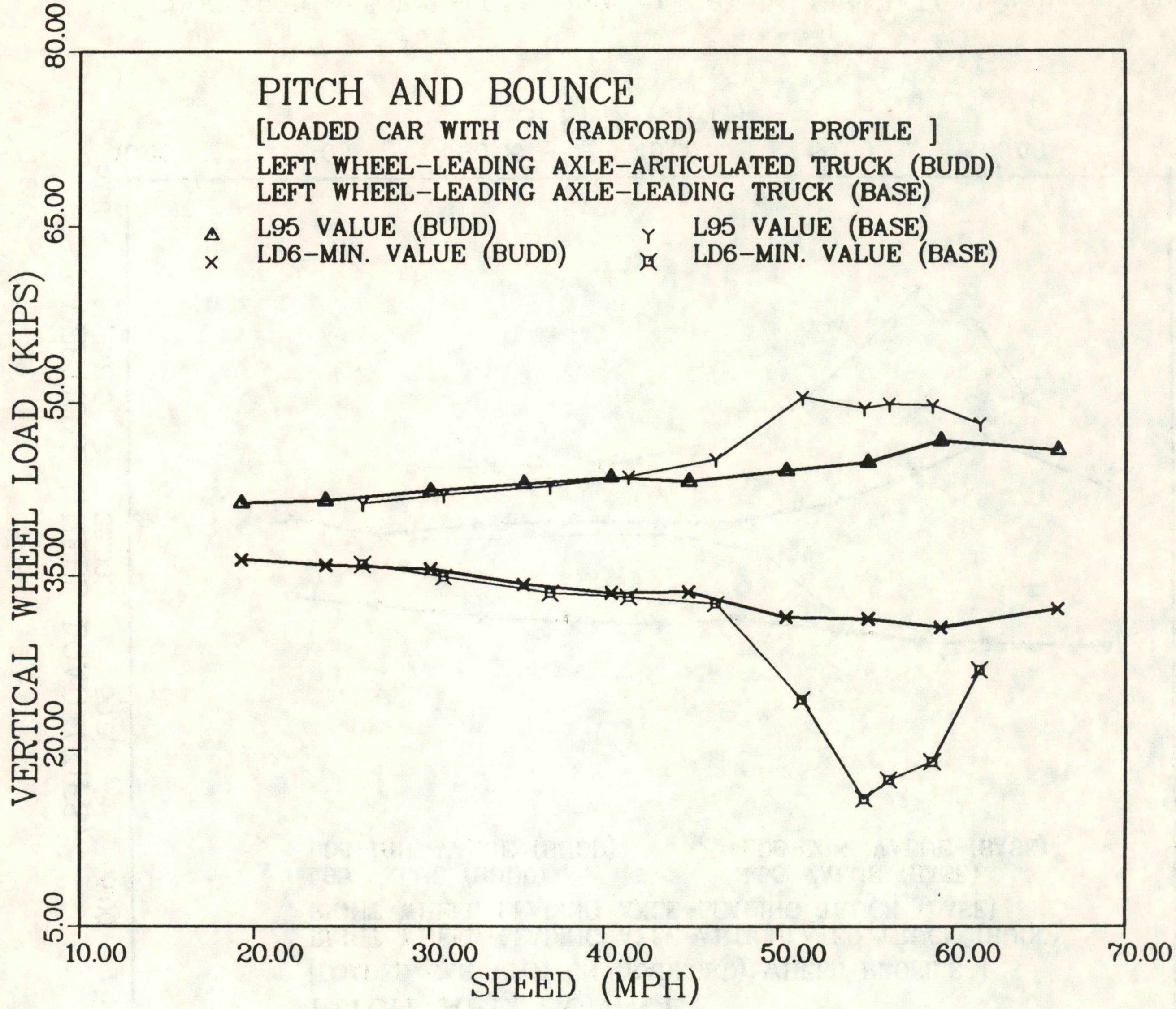


Figure 5.4: HI CUBE and Base Car Vertical Left Wheel Load *versus* Speed, Loaded Cars.

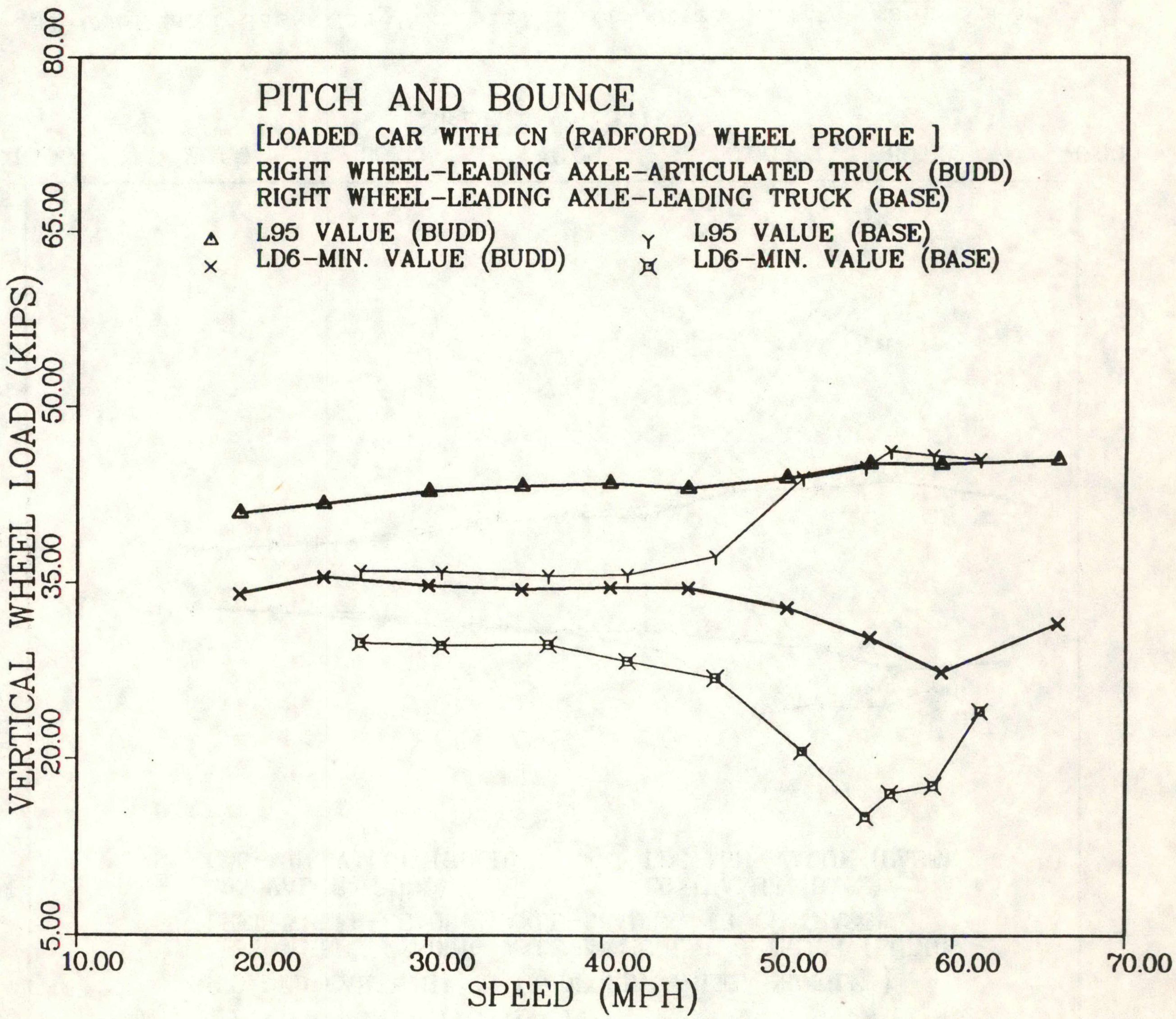


Figure 5.5: HI CUBE 2000 and Base Car Vertical Right Wheel Load <u>versus</u> Speed, Loaded Cars.

6.0 HUNTING REGIME

The hunting performance of the two vehicles were compared. Both vehicles had CN Heumann (Radford) wheel profiles. The tests were conducted for the empty car only. The test site for the hunting test included two contiguous tangent sections on the RTT track.

Figures 6.1 thru 6.3 show comparisons of the rms. carbody lateral accelerations and of axle rms. lateral accelerations in the 0-20 Hz frequency range. The base car results clearly show a sharp change in rms. acceleration levels after 40 mph, which corresponded to the start of hunting behavior. Up to this speed, the rms. acceleration levels for the HI CUBE 2000 were comparable with those of the base car. However, the base car tests were limited to about 60 mph, due to hard flange-to-flange hunting, whereas, the HI CUBE 2000 ran safely up to 75 mph. The acceleration levels, Figure 6.1, and observations during the tests indicated that the maximum speed for the comparable levels of hunting increased from 55.8 mph for the base car to over 75 mph for the HI CUBE 2000. It is seen that both units of the HI CUBE 2000 exhibit this improved hunting stability.

In considering rms. axle lateral accelerations, the articulated truck alone carries a vertical load comparable with the load on the two base car trucks. Hence, the acceleration levels are compared only for these axles, as seen in Figure 6.2.

However, for curiosity's sake, the lead truck lateral accelerations are also shown for comparison with the lead axle of the lead truck of the base car.

An assessment of the lateral loads is also included here. Figures 6.4 and 6.5 show the L95 value of the lateral wheel load for the lead axles (both wheels) of the lead truck and the articulated truck. It can be seen that the increased stability of the HI CUBE 2000 is manifested in the reduction of lateral loads.

In summary, it can be seen that the HI CUBE 2000 has vastly improved stability up to 75 mph as compared with the base car.

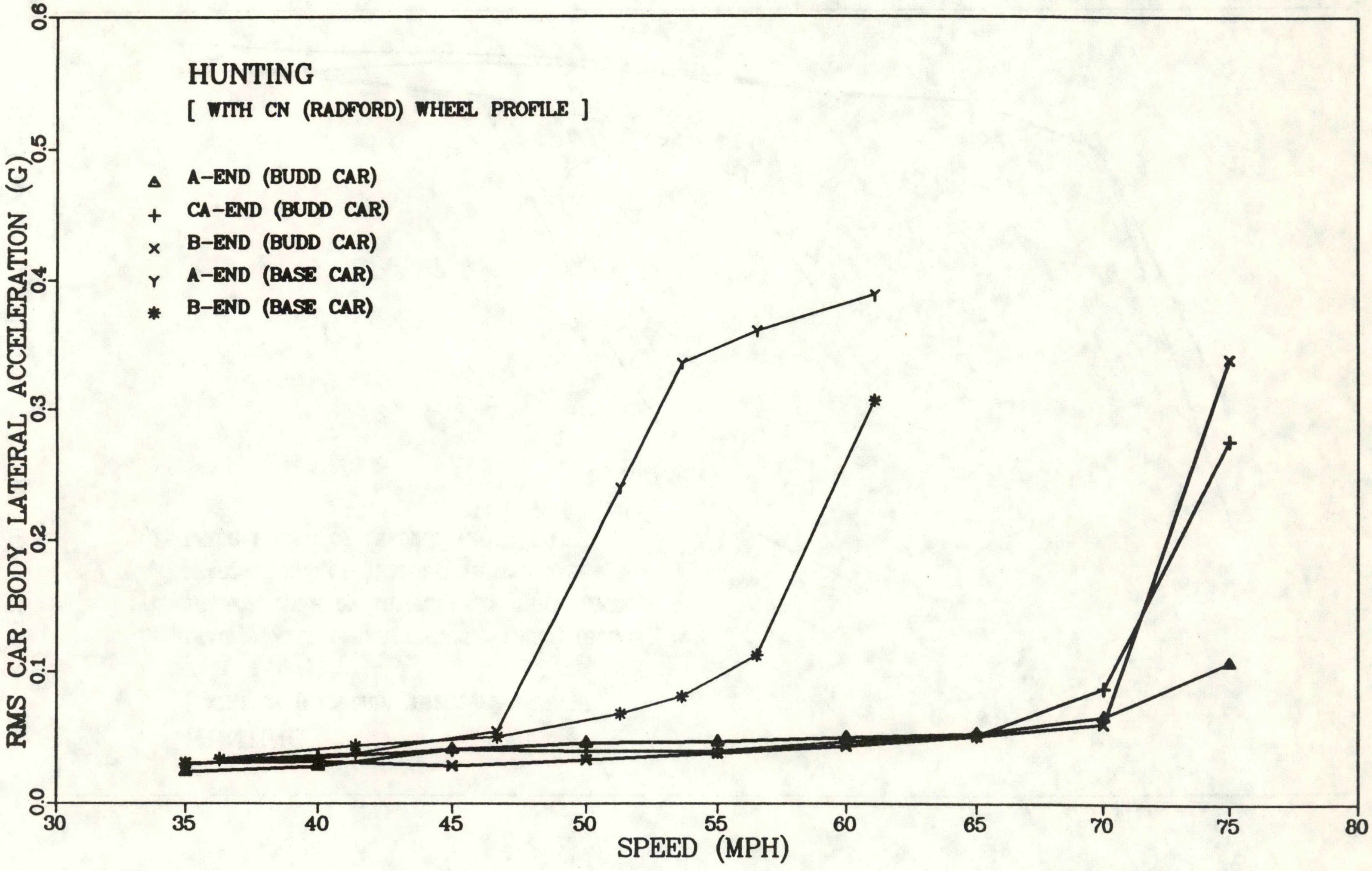


Figure 6.1: HI CUBE 2000 and Base Car RMS Carbody Lateral Acceleration <u>versus</u> Speed, CN (Radford) Profiles, Empty Car

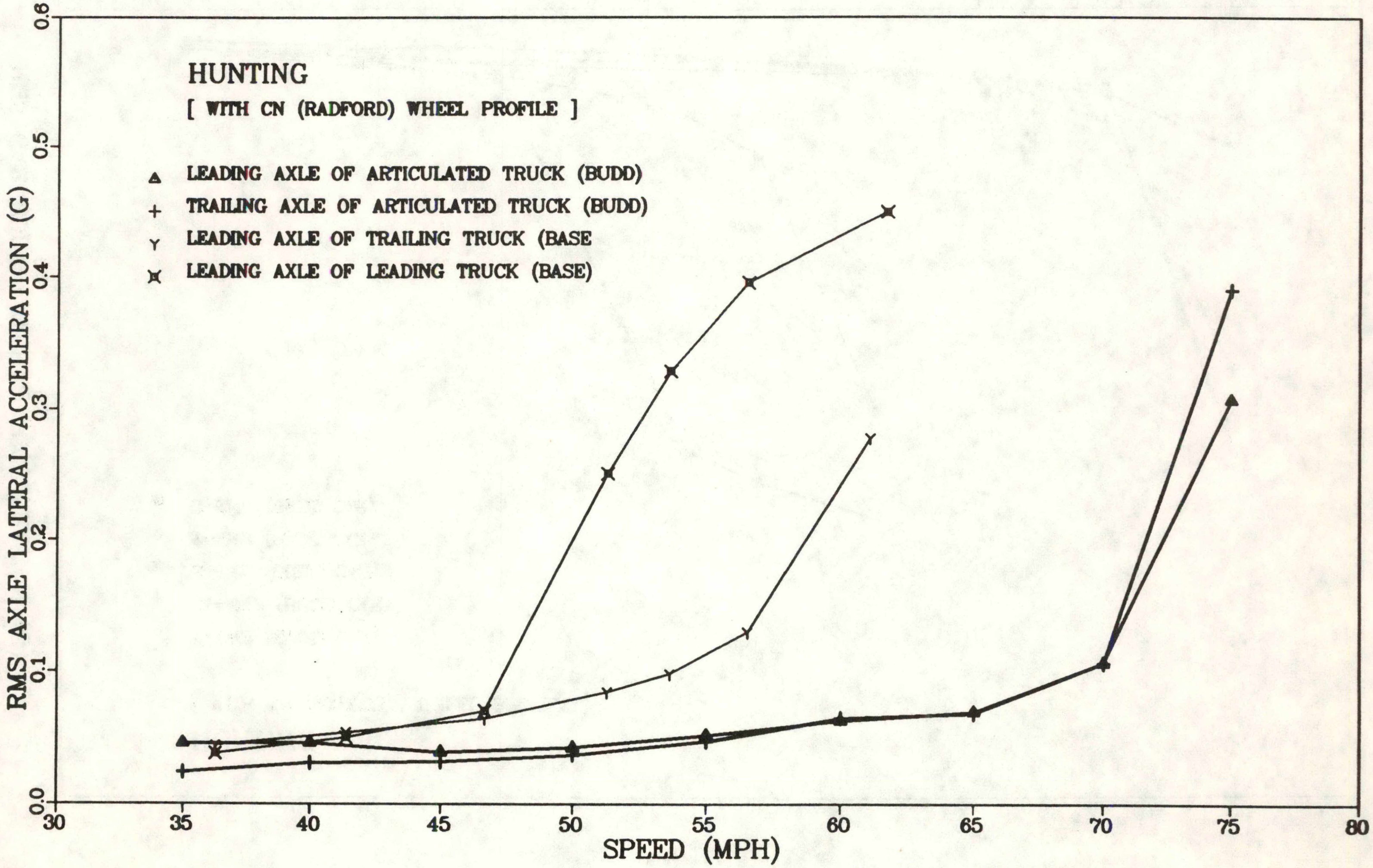


Figure 6.2: HI CUBE 2000 and Base Car RMS Axle Lateral Acceleration <u>versus</u> Speed, CN (Radford) Profiles, Empty Car.

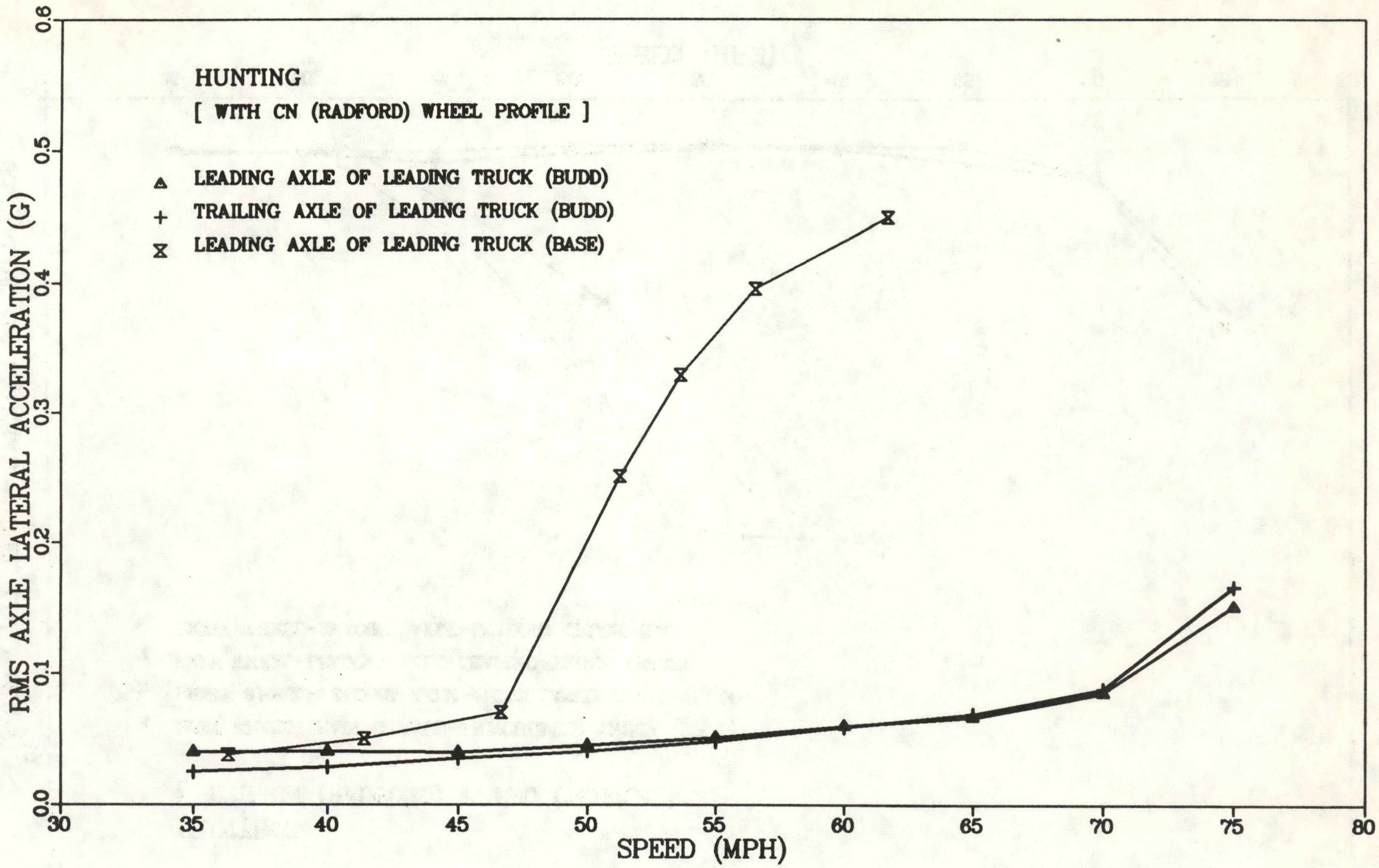


Figure 6.3: HI CUBE 2000 and Base Car, RMS Axle Lateral Acceleration <u>versus</u> Speed, CN (Radford) Profiles, Empty Car.

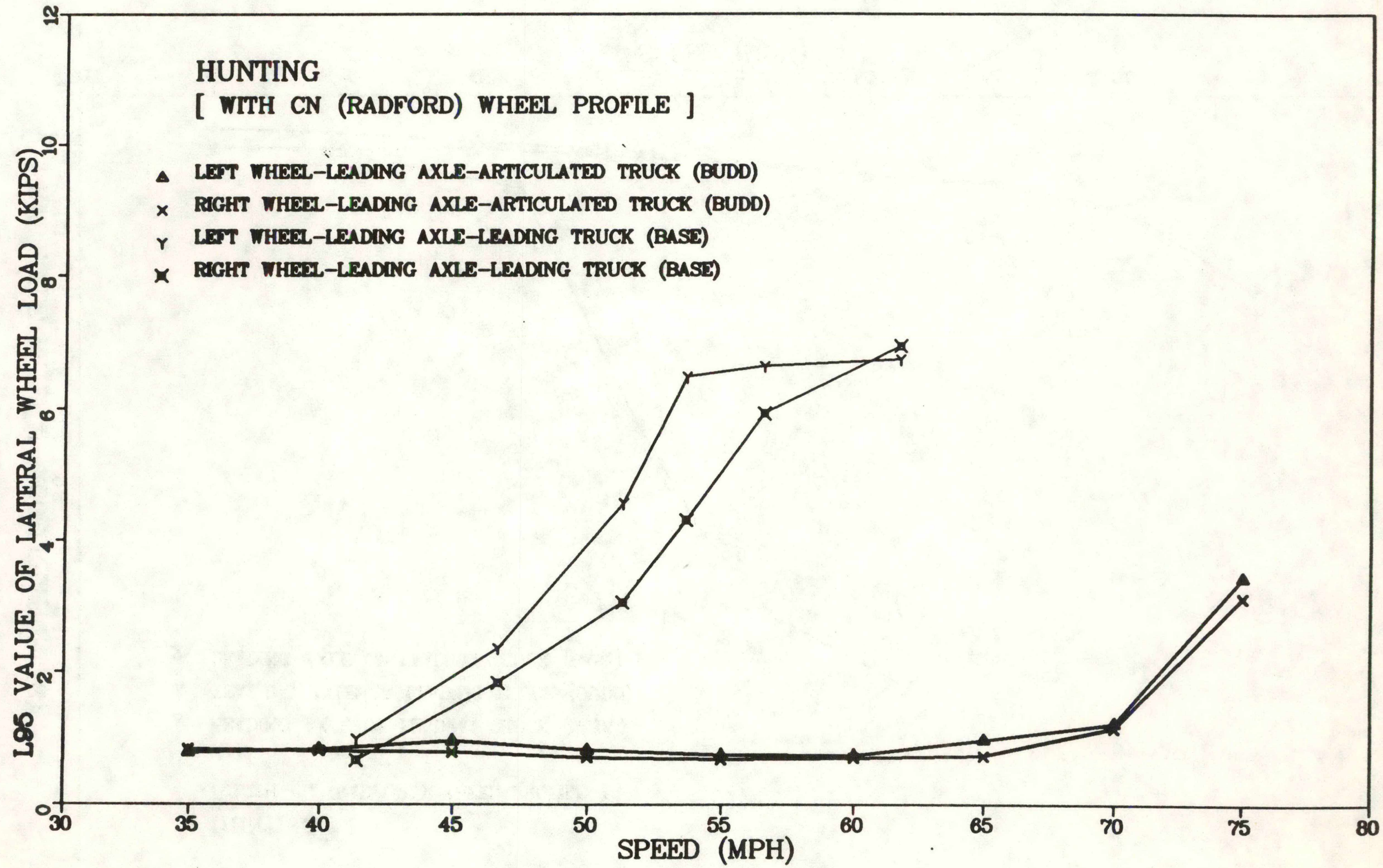


Figure 6.4: HI CUBE 2000 and Base Car Lateral Wheel Load (L95 value) versus Speed, CN (Radford) Profiles, Empty Car.

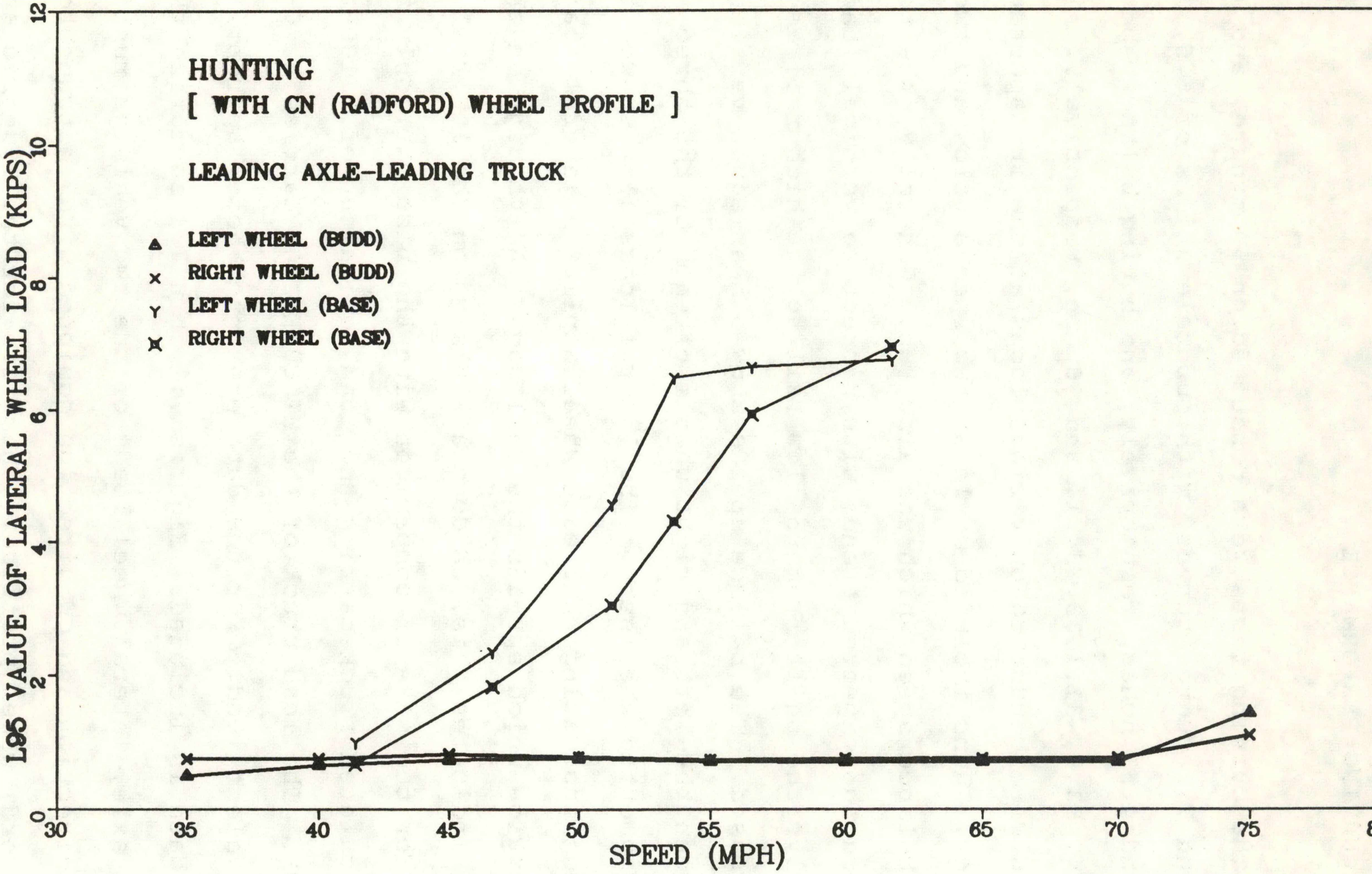


Figure 6.5: HI CUBE 2000 and Base Car Lateral Wheel Load (L95 value) versus Speed, CN (Radford) Profiles, Empty Car.

7.0 CURVING PERFORMANCE

The curving tests were conducted on 50 minute, and 1.5, 3, 4, 5, and 7.5 degree curves, with superelevations of 6.5, 3, 2, 3, 4, and 4.5 inches, respectively, and having balance speeds of 106.4, 53.9, 31.1,33, 34.1, and 30 mph, respectively. These tests were conducted on various loops at the Transportation Test Center. Runs included at least two speeds below and two above the balance speed which was also run. Generally, the test data showed the expected trends with respect to vertical loads; namely, the shift from the low rail to the high rail as the speed increased. The balance speeds showed near equal vertical loads between the left and right wheels of each of the three instrumented wheelsets. The lateral loads also showed the normal trends indicating that each wheel applies a lateral load in a direction which spreads the rail gage. A +ve sign on the high rail indicates this, as does a -ve sign on the low rail.

For the sake of comparison with the base car, only the articulated truck carries the load equivalent of a 100-ton truck. The lead truck of the HI CUBE 2000 carries a 70-ton truck equivalent load. For the data presented here, appropriate base car data is included. Figures 7.1 thru 7.4 summarize the mean, lead axle, lateral wheel loads of the two vehicles running in the CCW direction and CW direction equipped with instrumented CN (Radford) wheel profiles. These are for the 3-degree and the 5-degree curve as a function of speed. For the HI CUBE 2000, the lead axle of the articulated truck is used for the comparison.

The base car mean lateral loads for the 50 minute curve (not shown) had an increase after 60 mph, due to the vehicle hunting. The mean lateral loads for the other curves (not shown) indicate that the HI CUBE 2000 had comparable lateral loads to the base car.

A summary of the clockwise and the counter clockwise data for the HI CUBE 2000 is presented for all the curves at balance speed. This includes mean lateral loads (Figures 7.5 thru 7.8), $L/_V$ ratios (Figure 7.9 thru 7.12) and mean angle-of-attack (Figures 7.13 and 7.14). Appropriate base car data is included in each of the plots.

As seen in Figure 7.5, the HI CUBE 2000 lead axle articulated truck has mean lateral loads comparable with the lead axle lead truck of the base car in the clockwise direction, while they are slightly higher in the counter clockwise direction (Figure 7.7). There are some differences for the trailing axles also (Figures 7.6 and 7.8).

The mean $L/_V$ ratios are shown in Figures 7.9 thru 7.12. and the angle-of-attack in Figure 7.13 and 7.14.

The articulated truck, in general, can be said to be comparable to the base car lead truck with respect to curving performance. For conditions, with heavy buff load, the articulated truck, we suspect, would behave the same while the base car truck would exhibit higher lateral loads.

The lead truck, with one lead instrumented wheelset showed results similar to a 70-ton truck.

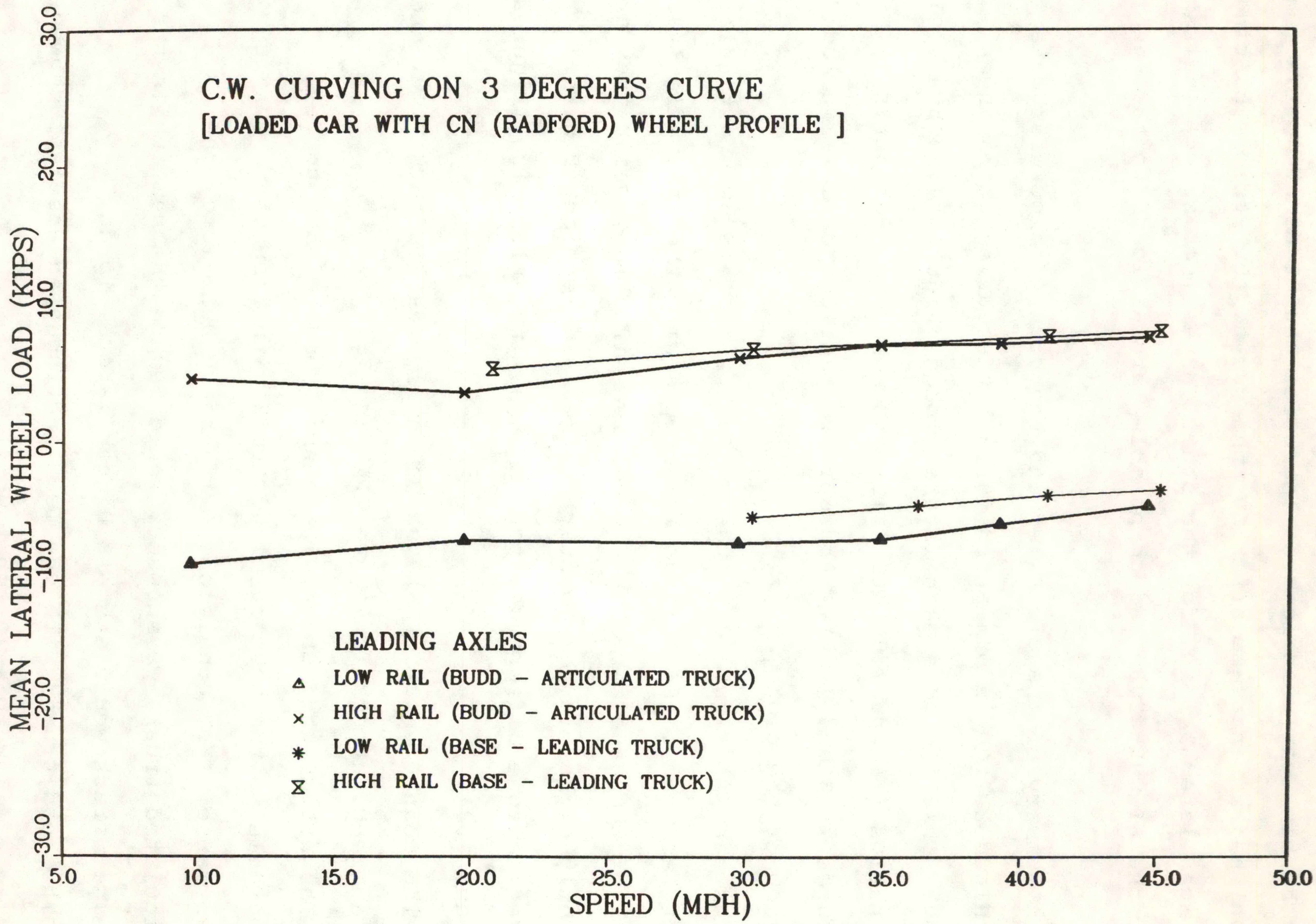


Figure 7.1: HI CUBE 2000 and Base Car Mean Lateral Wheel Load <u>versus</u> Speed, 3 degree Curve, Clockwise, Loaded.

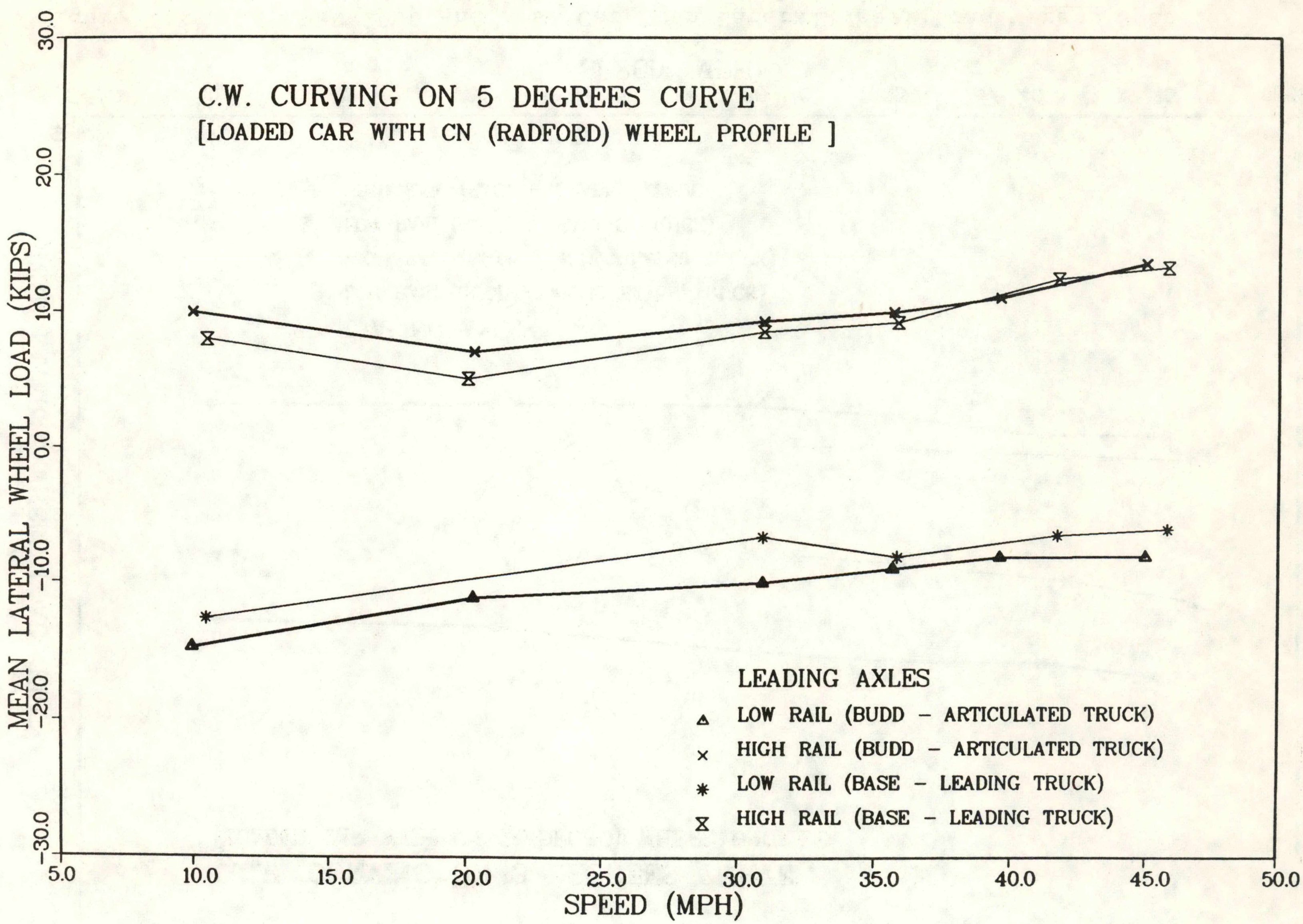


Figure 7.2: HI CUBE 2000 and Base Car Mean Lateral Wheel Load <u>versus</u> Speed, 5 degree Curve, Clockwise, Loaded.

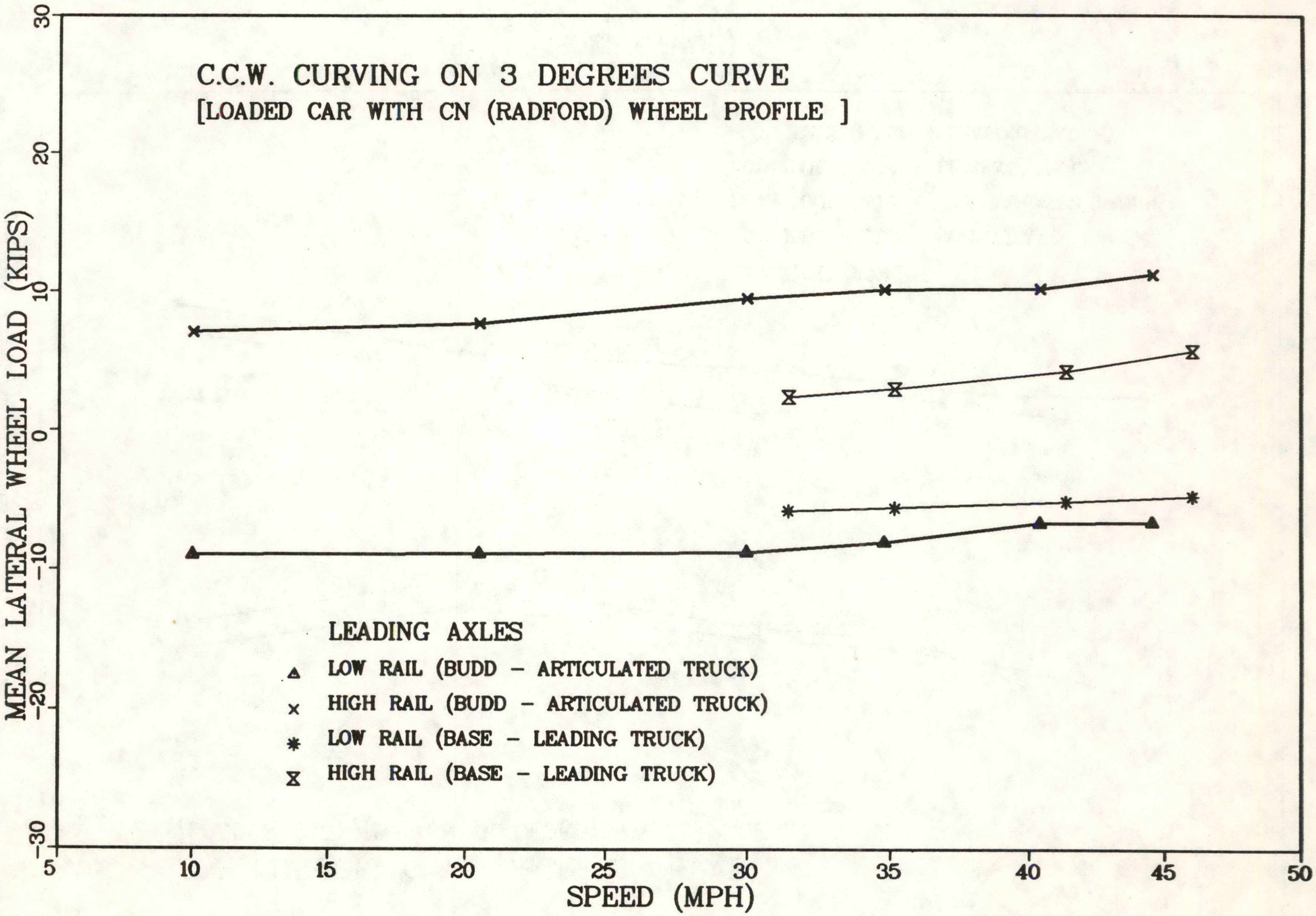


Figure 7.3: HI CUBE 2000 and Base Car Mean Lateral Wheel Load versus Speed, 3 degree Curve, Counter Clockwise, Loaded.

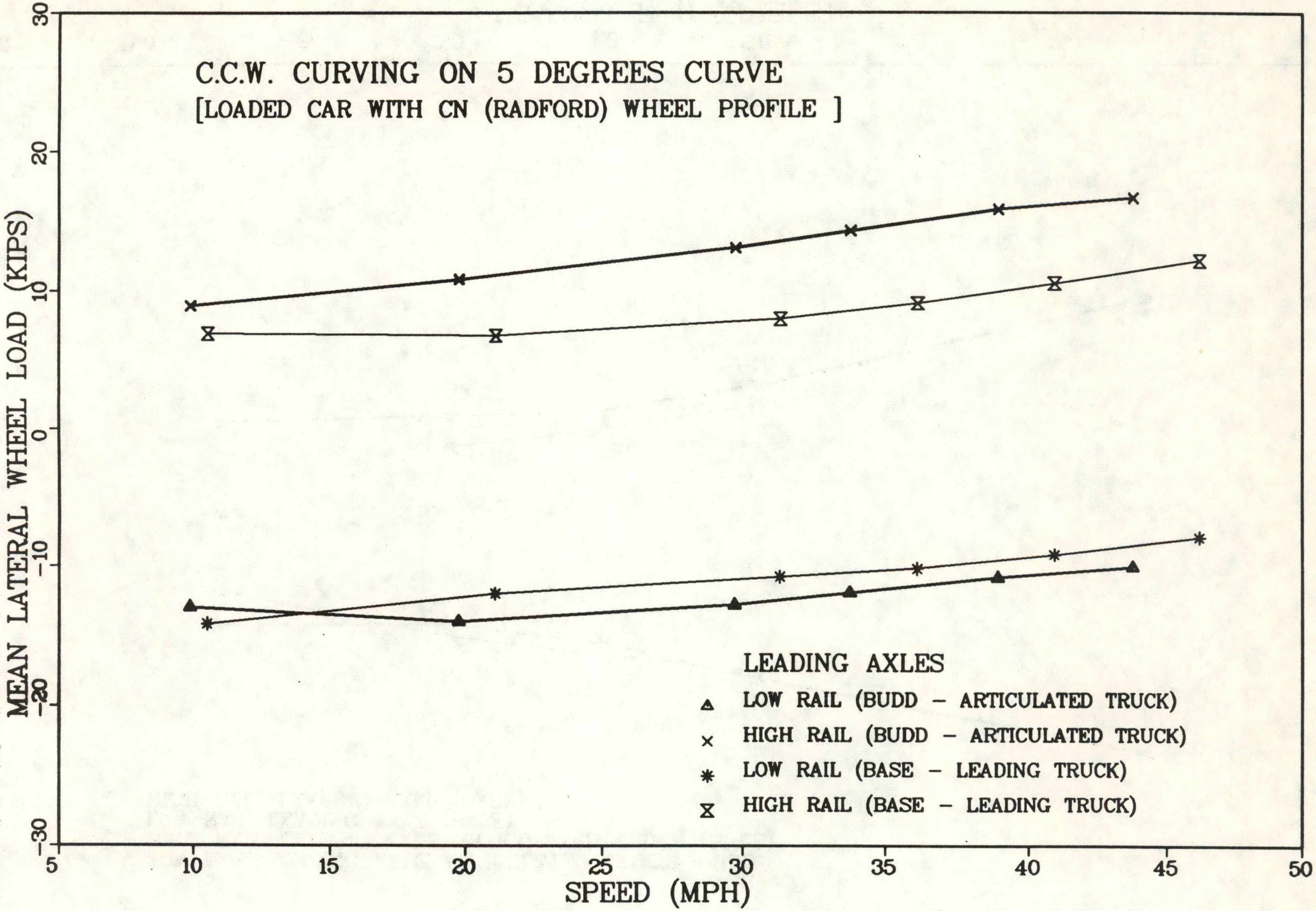


Figure 7.4: HI CUBE 2000 and Base Car Mean Lateral Wheel Load <u>versus</u> Speed, 5 Degree Curve, Counter Clockwise, Loaded.

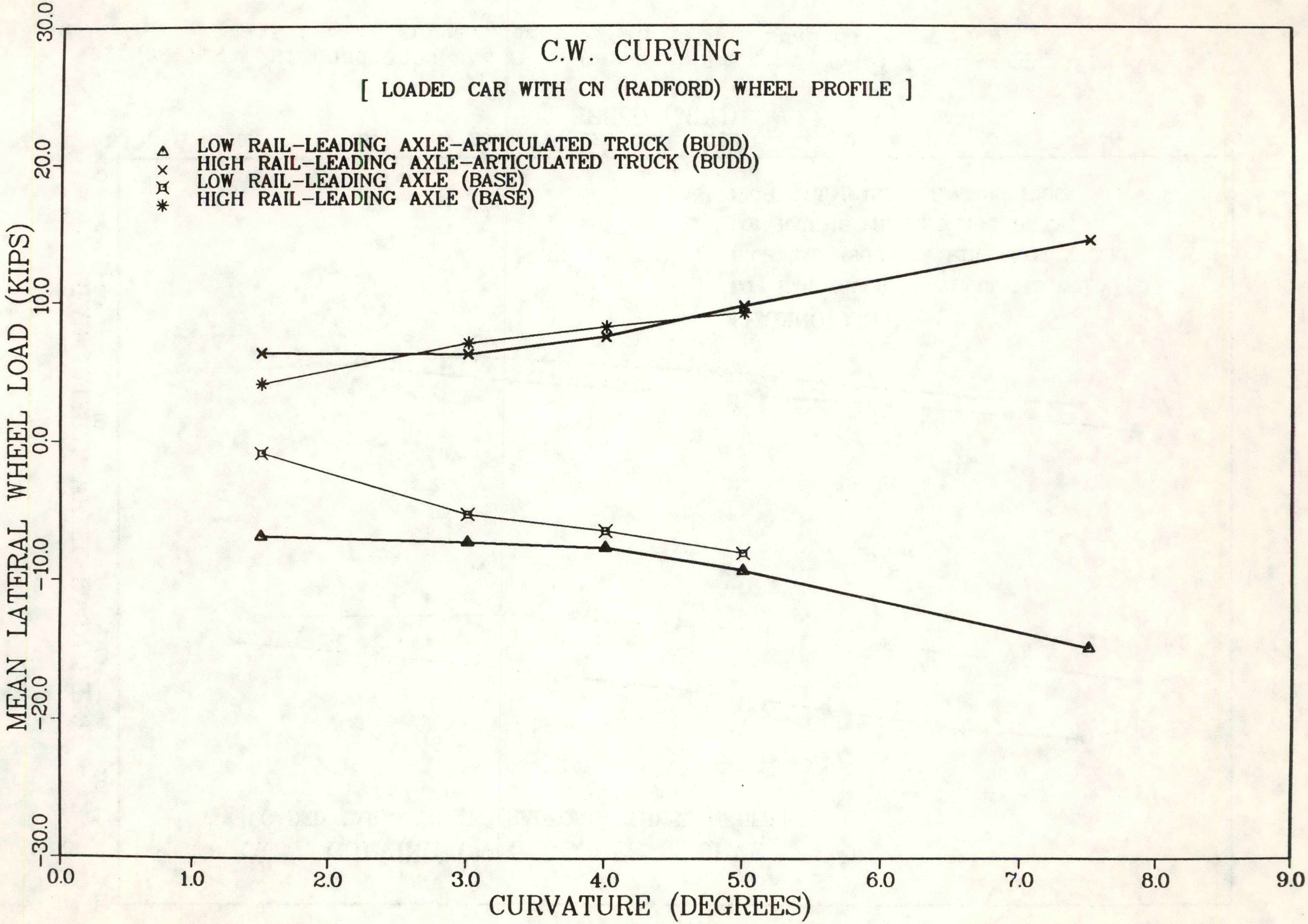


Figure 7.5: HI CUBE 2000 and Base Car Mean Lateral Wheel Load on Leading Axle <u>versus</u> Curvature at Balance Speed, Clockwise, Loaded.

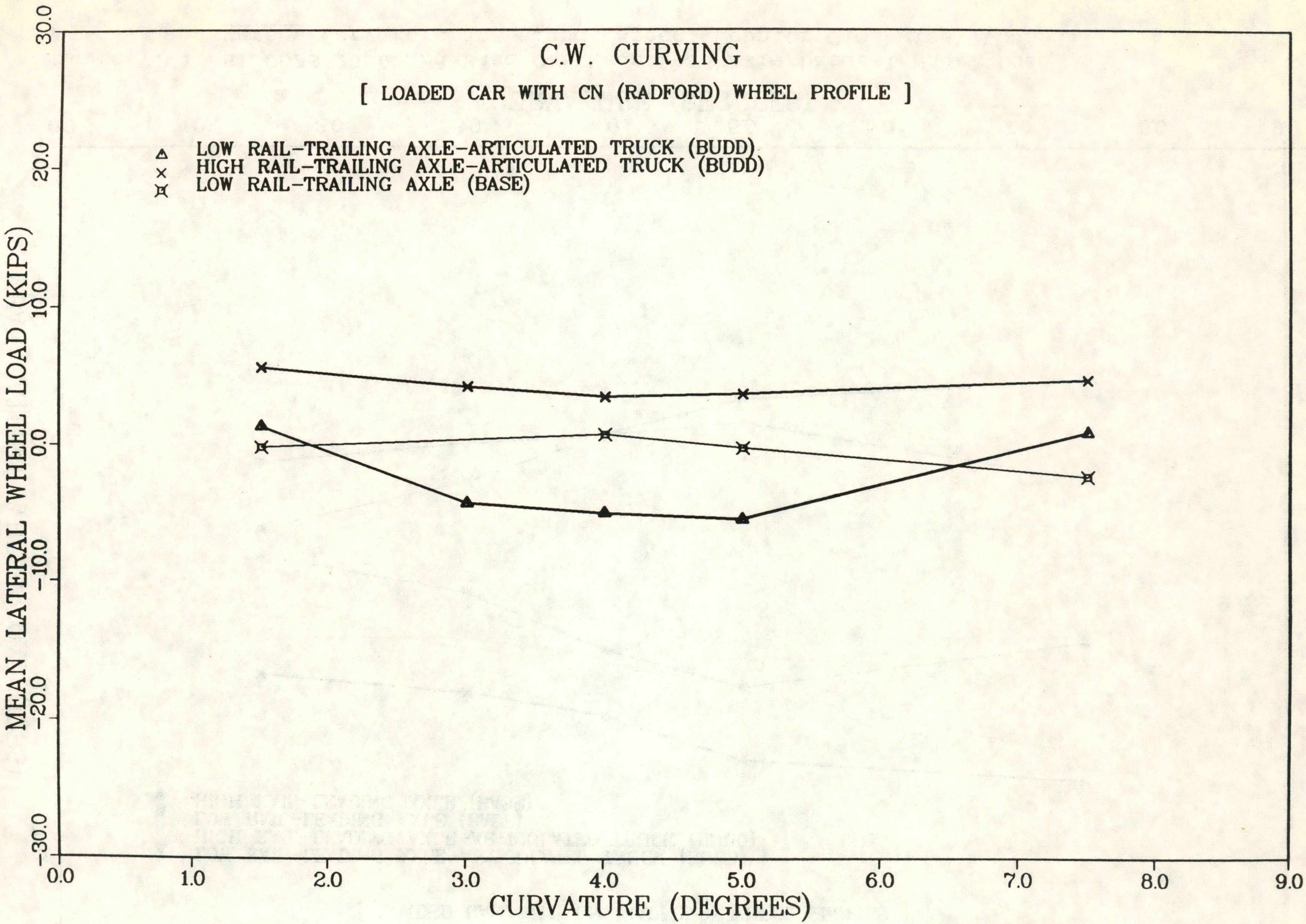


Figure 7.6: HI CUBE 2000 and Base Car, Mean Lateral Wheel Load on Trailing Axle <u>versus</u> Curvature at Balance Speed, Clockwise, Loaded.

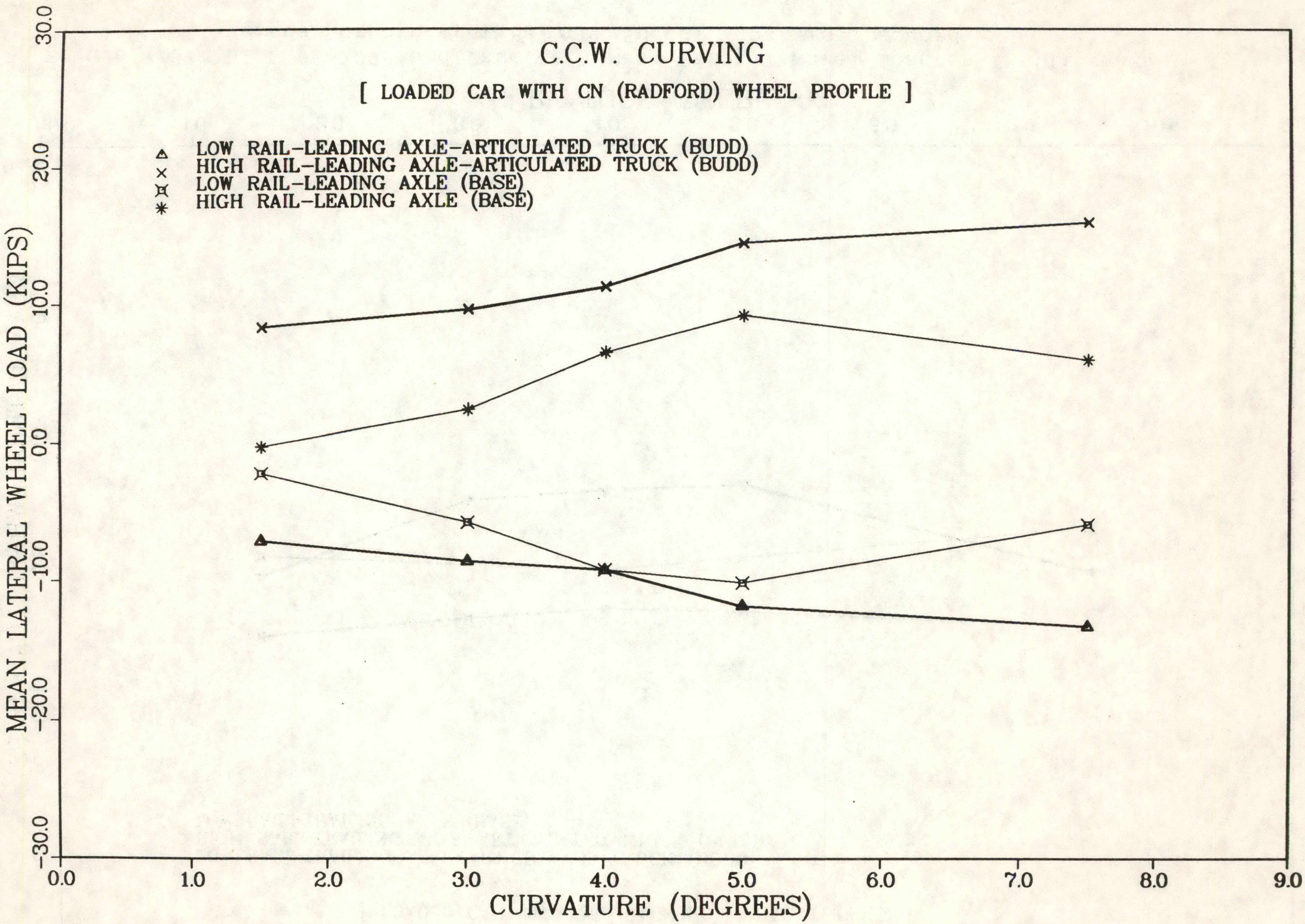


Figure 7.7: HI CUBE 2000 and Base Car Mean Lead Axle Lateral Wheel Load <u>versus</u> Curvature at Balance Speed, Counter Clockwise, Loaded.

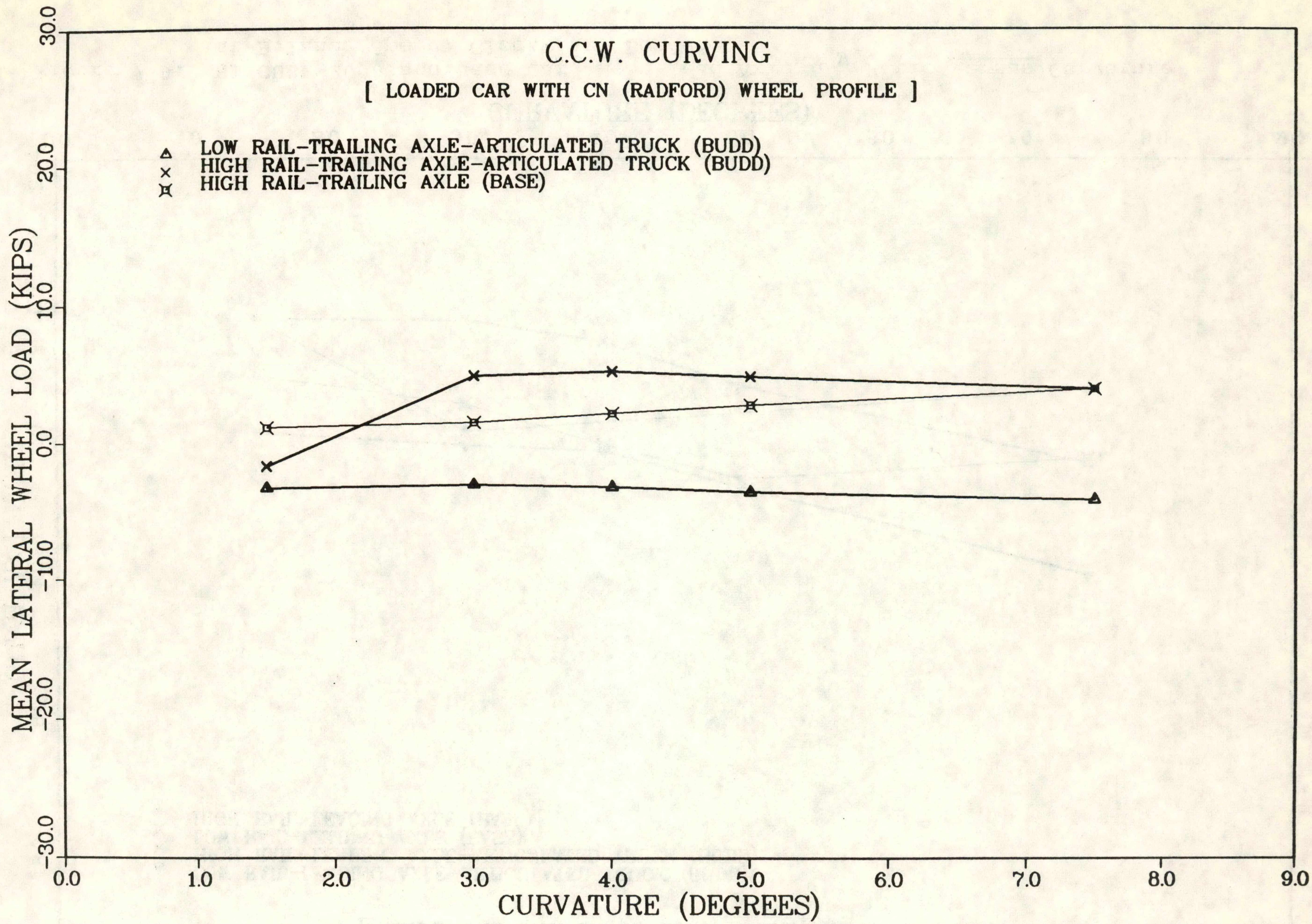


Figure 7.8: HI CUBE 2000 and Base Car Mean Trail Axle Lateral Wheel Load <u>versus</u> Curvature at Balance Speed, Counter Clockwise, Loaded.

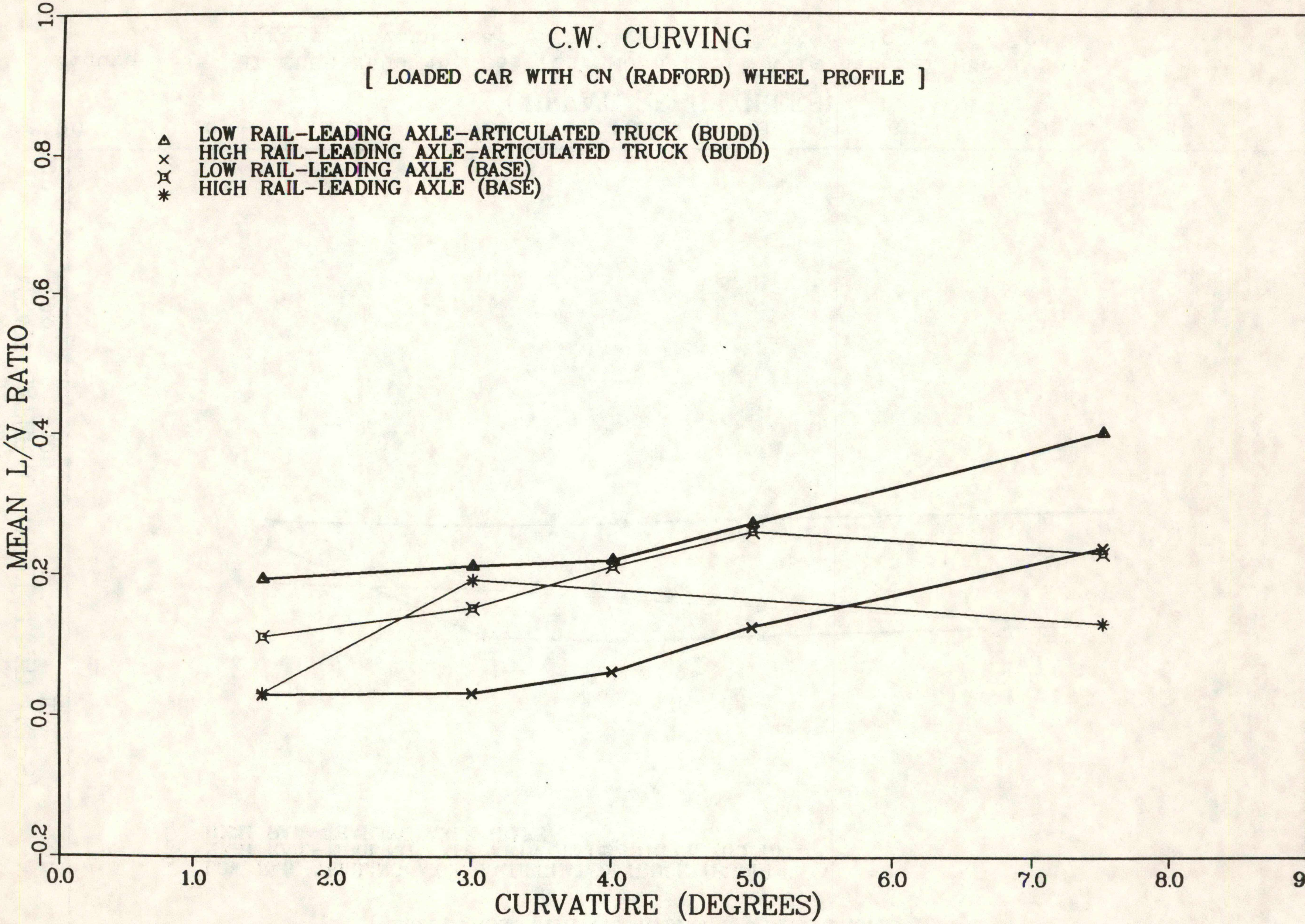


Figure 7.9: HI CUBE 2000 and Base Car, Mean lead Axle $L/_V$ Ratio versus Curvature at Balance Speed, Clockwise, Loaded.

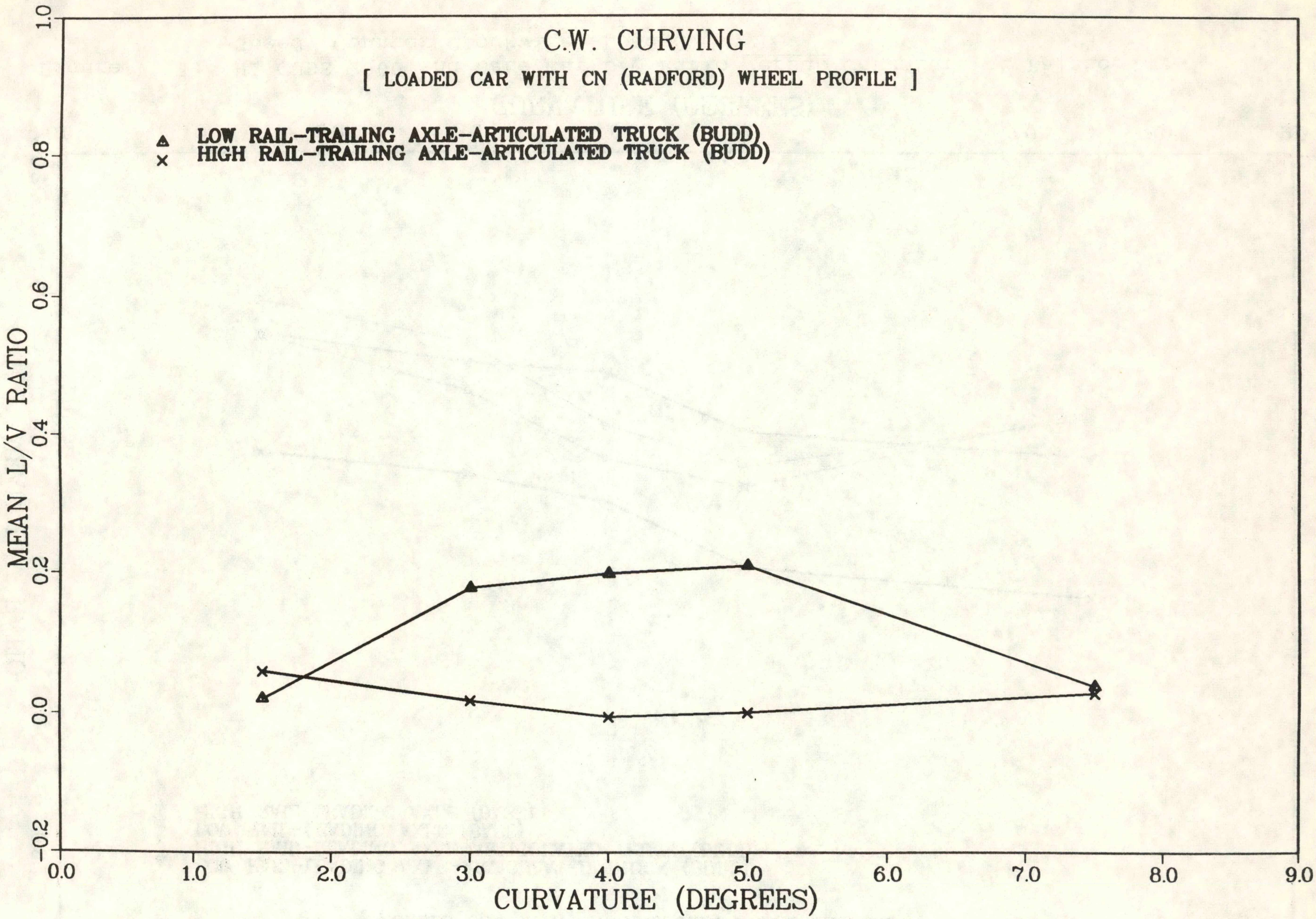


Figure 7.10: HI CUBE 2000 Mean Trail Axle $L/_V$ Ratio versus Curvature at Balance Speed, Clockwise, Loaded.

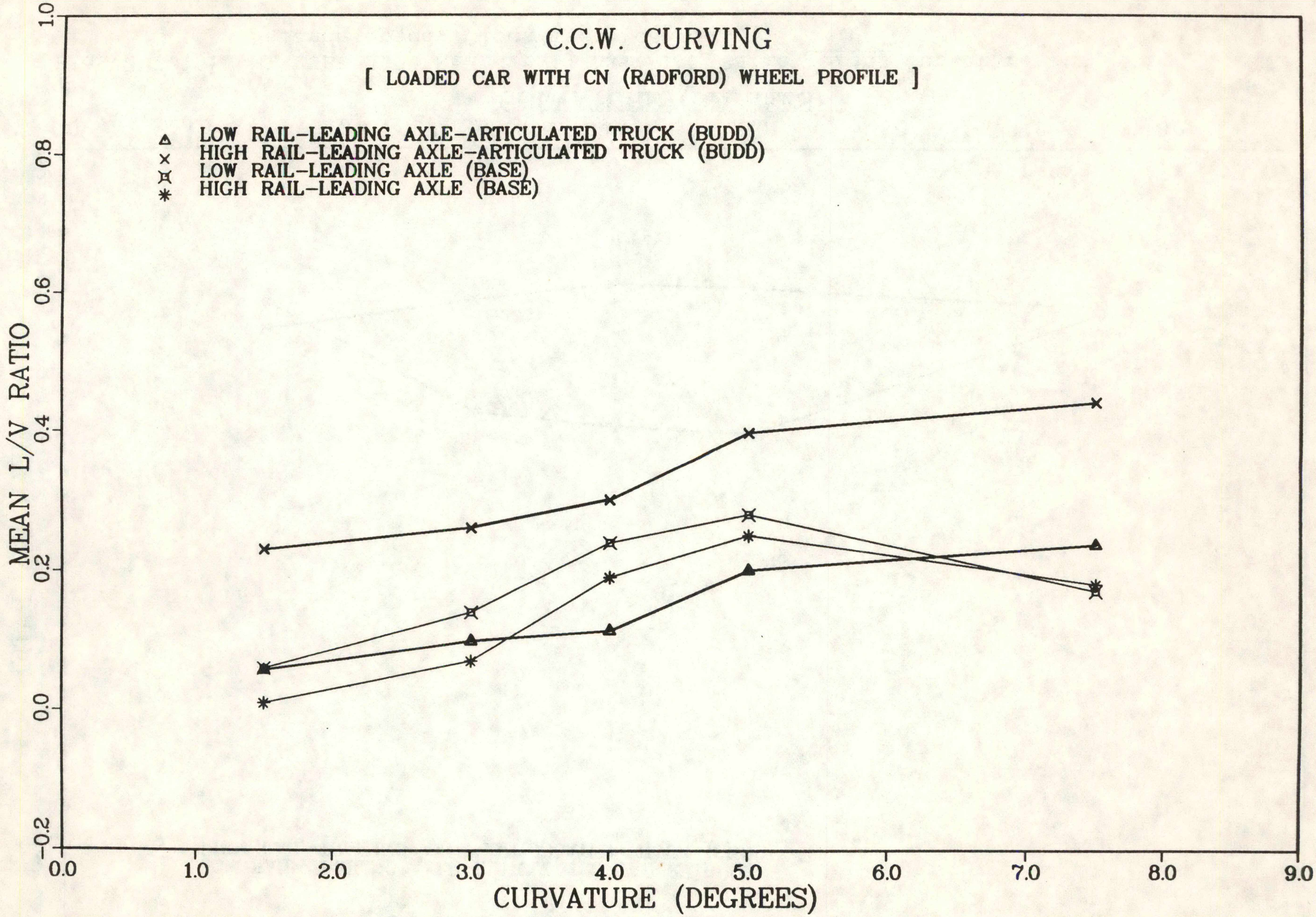


Figure 7.11: HI CUBE 2000 and Base Car L/V Ratio *versus* Curvature at Balance Speed, Counter Clockwise, Loaded.

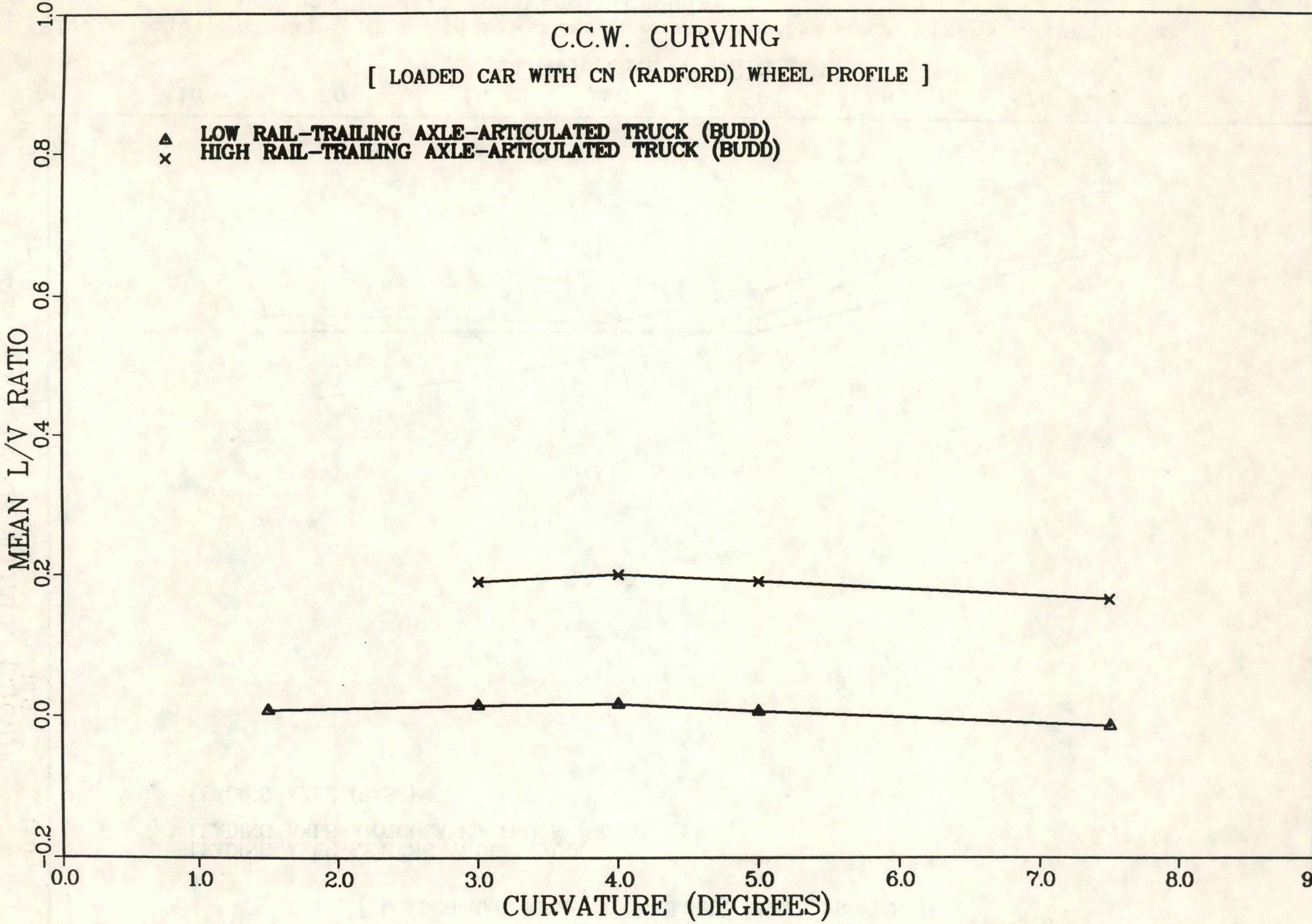


Figure 7.12: HI CUBE 2000 Mean L/V Ratio *versus* Curvature at Balance Speed, Counter Clockwise, Loaded.

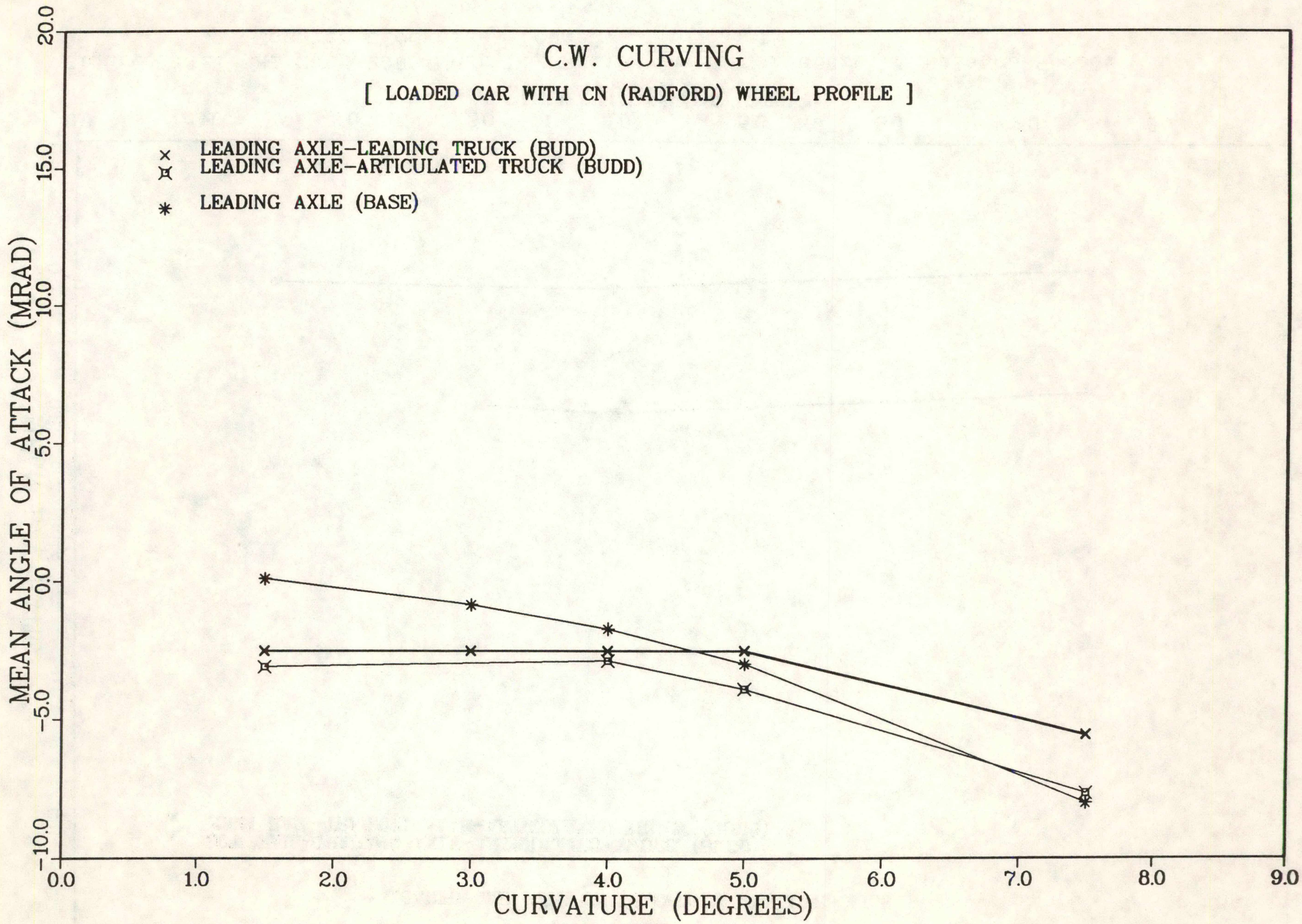


Figure 7.13: HI CUBE 2000 and Base Car Mean Angle-of-Attack <u>versus</u> Curvature at Balance Speed, Clockwise, Loaded.

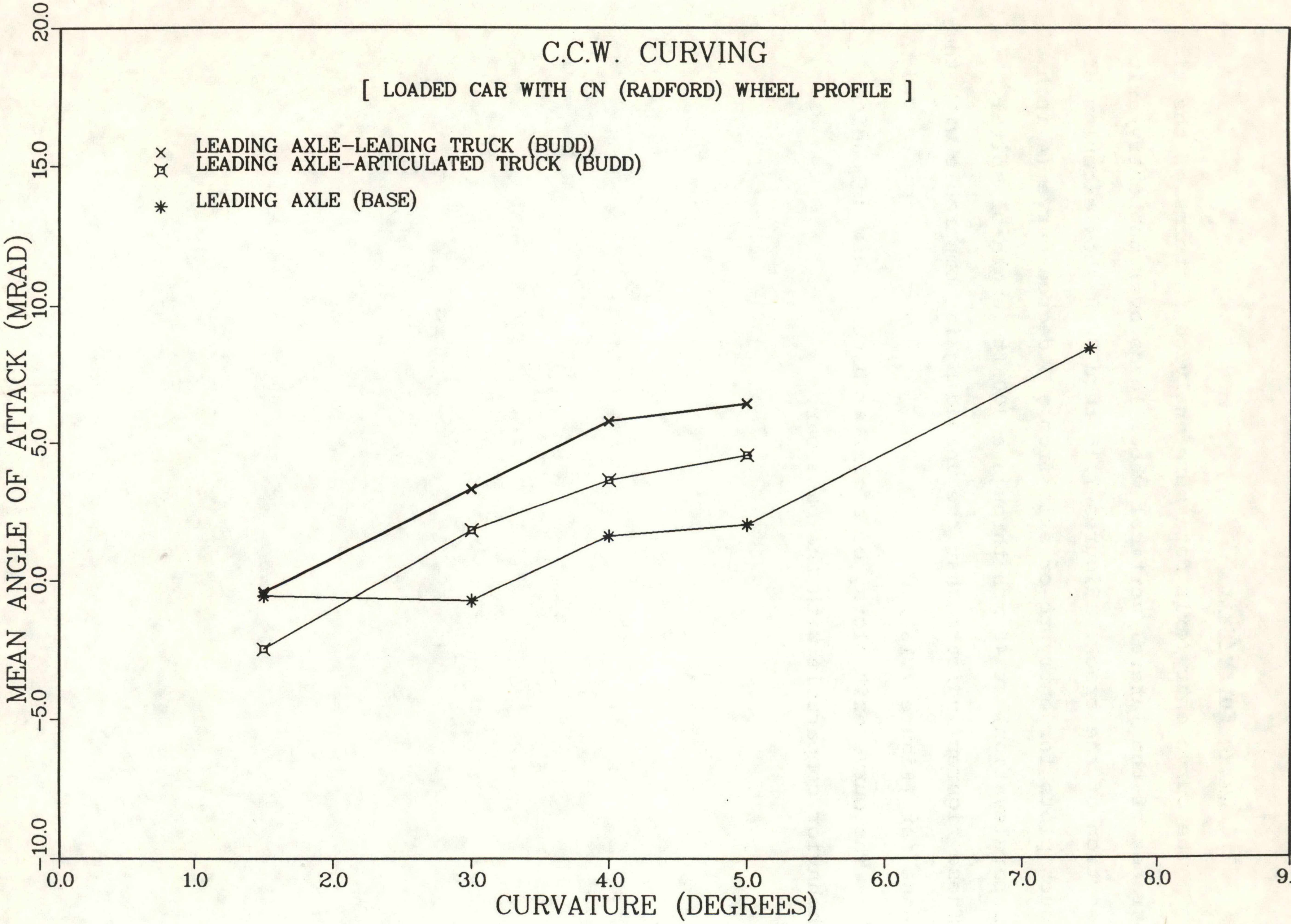
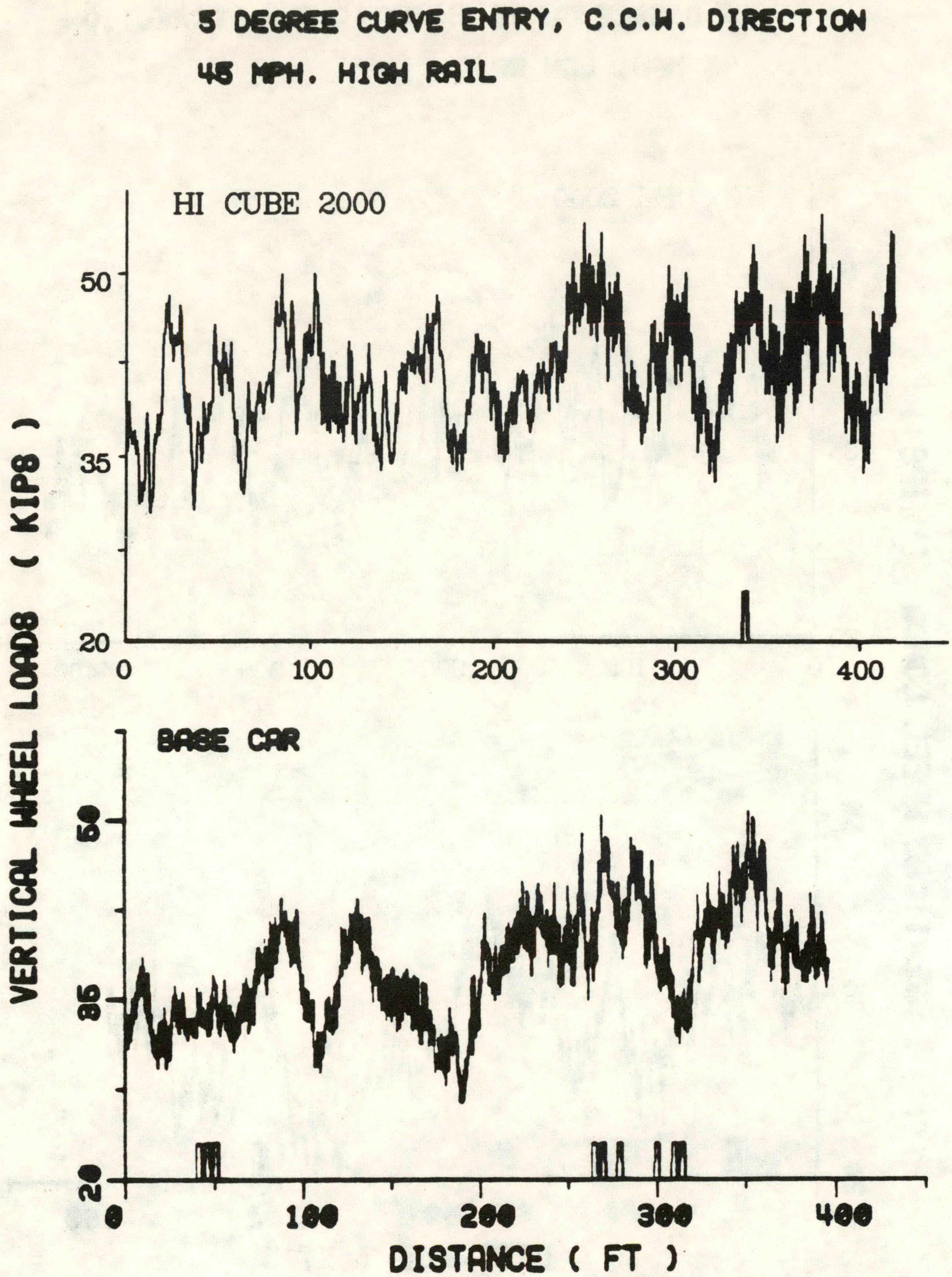


Figure 7.14: HI CUBE 2000 and Base Car Mean Angle-of-Attack <u>versus</u> Curvature at Balance Speed, Counter Clockwise, Loaded.

7.1 Curve Entry/Exit

The curve entry/exit data were analyzed in terms of the time traces of the lateral/vertical wheel loads over the entry/exit section of the track. Figures 7.15 thru 7.18 show examples of such plots for entry to or exit from a 5 degree curve (4 inch superelevation) at 45 mph through a 300 ft length of spiral. These figures indicate that the unloading is comparable with the base car (Figure 7.16).

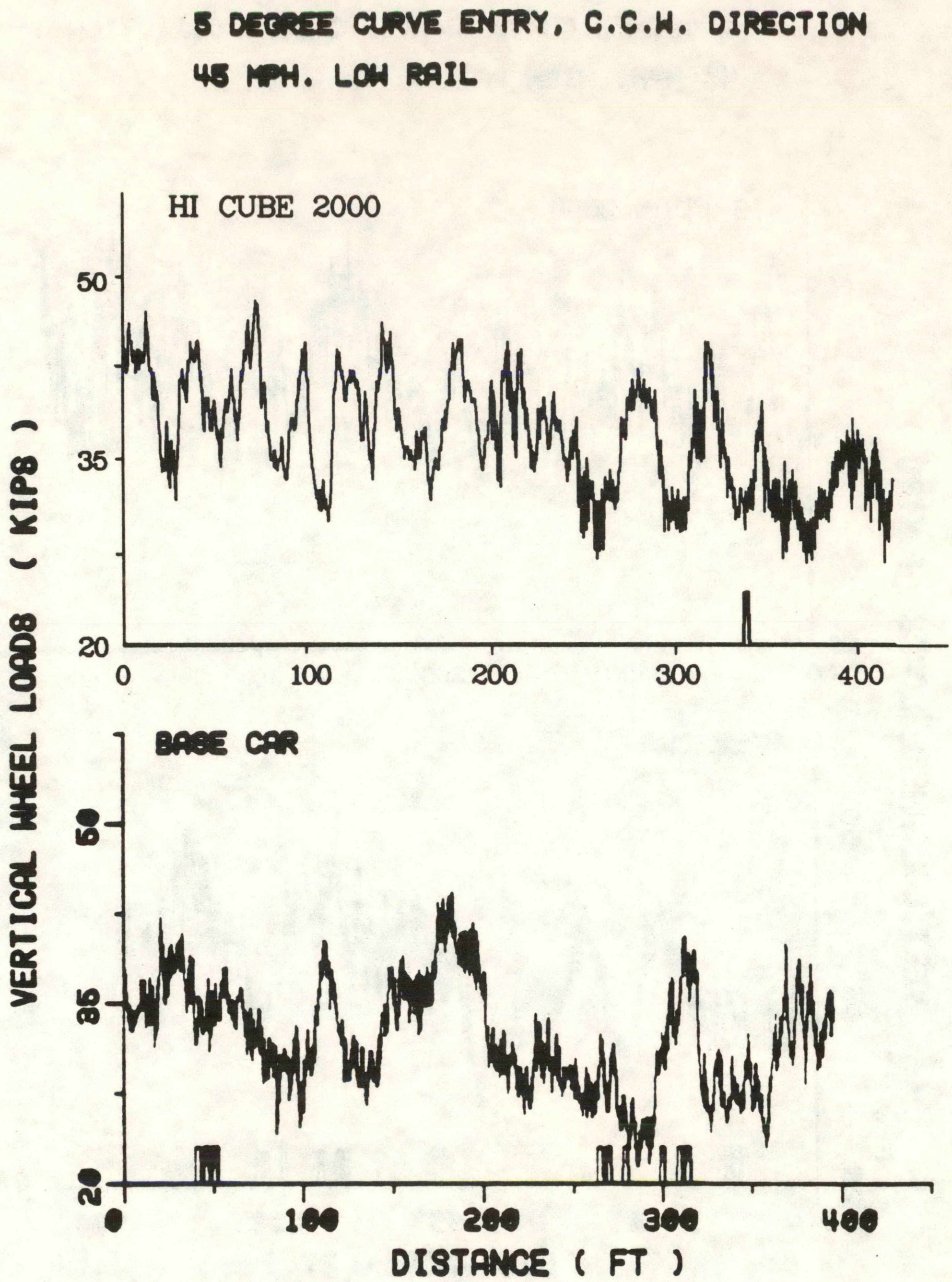
The curve exit plots, of a similar nature show unloading behavior comparable with the base car.



HI CUBE 2000: Leading Axle
Articulated Truck

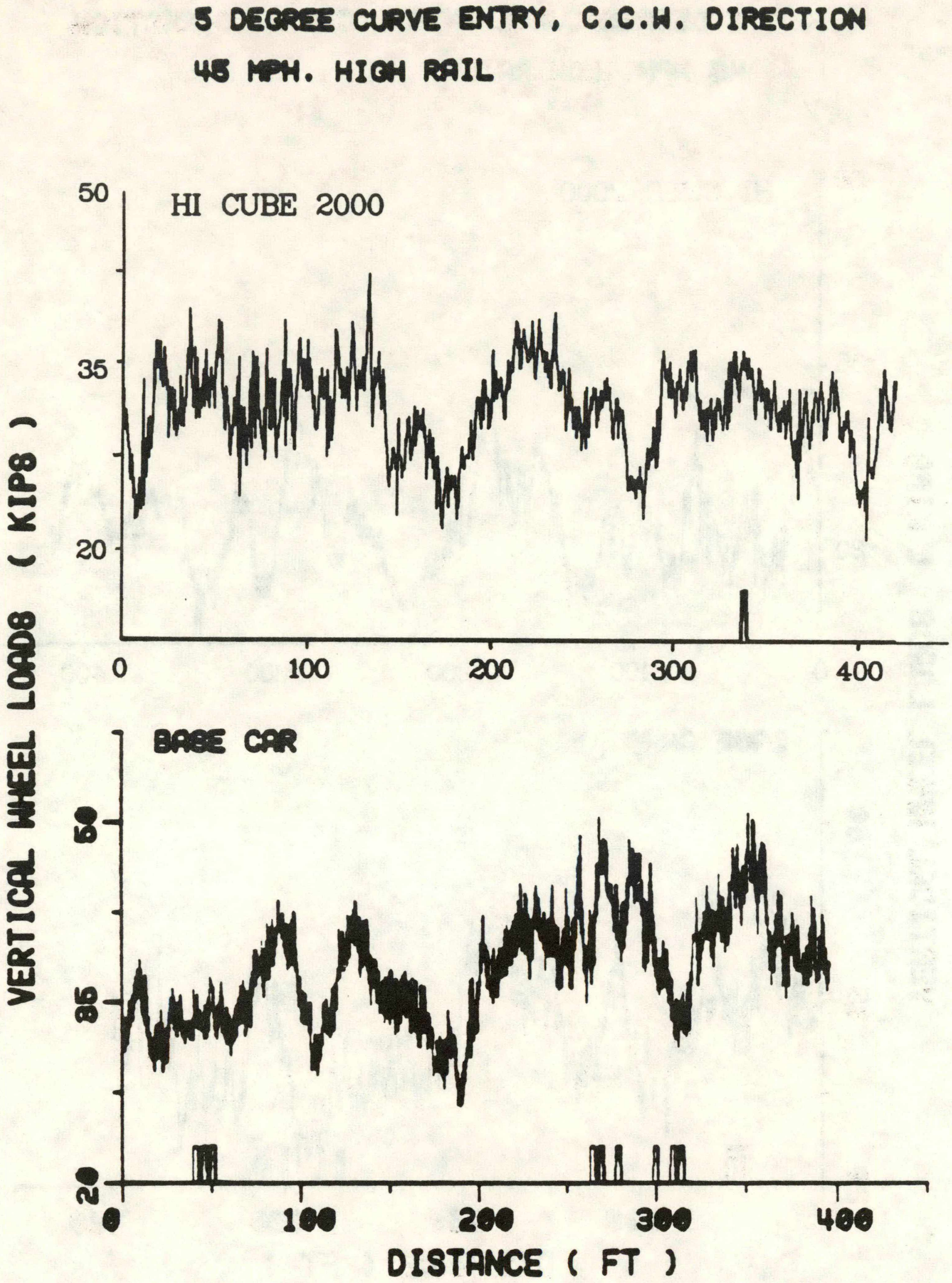
Base: Leading Axle
Leading Truck

Figure 7.15: High Rail Vertical Load Time Traces for the HI CUBE 2000 and Base Cars, During 5 degree Curve Entry at 45 mph.



HI CUBE 2000: Leading Axle, Articulated Truck
Base: Leading Axle, Leading Truck

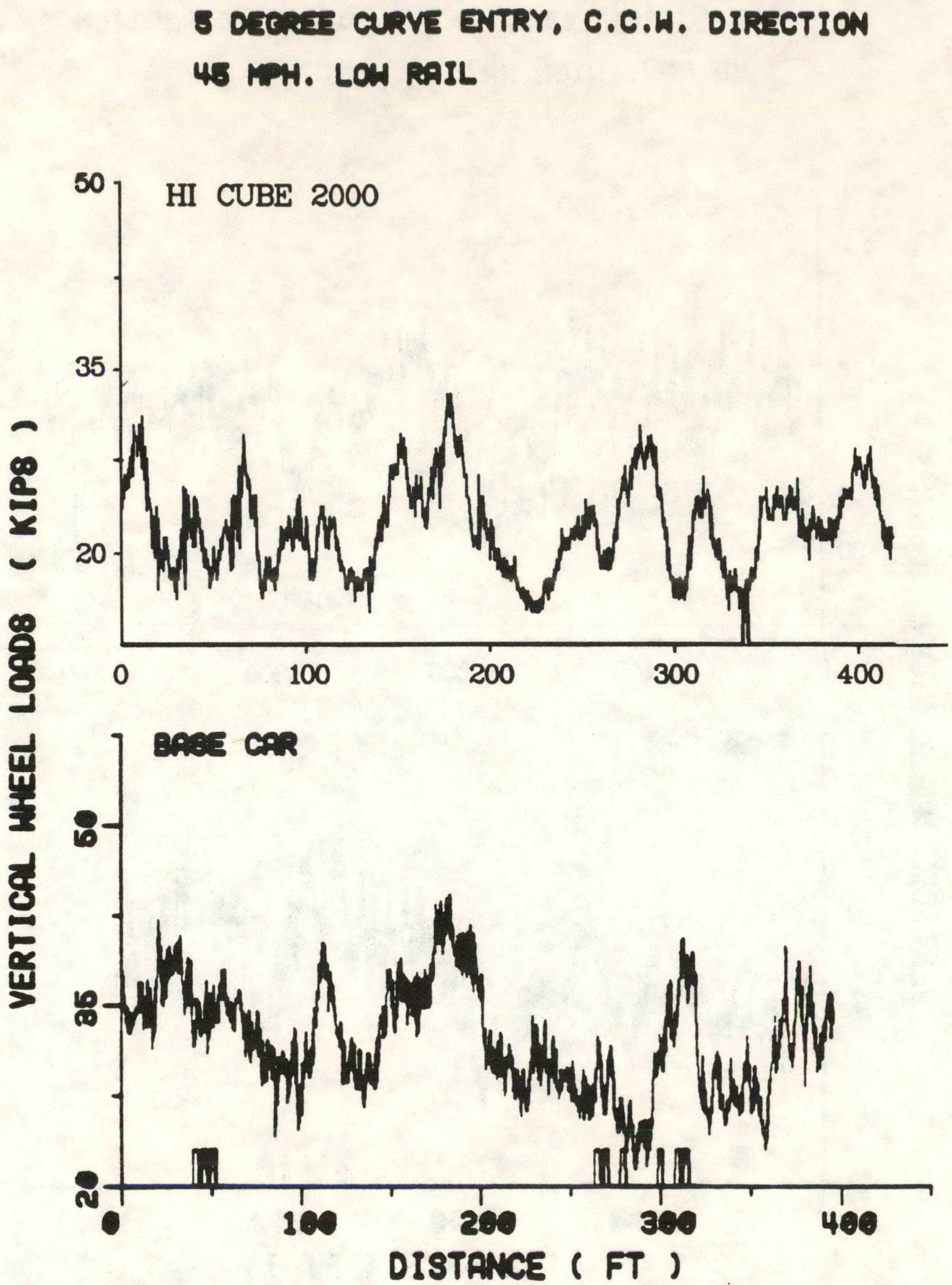
Figure 7.16: Low Rail Vertical Load Time Traces for the HI CUBE 2000 and Base Cars, During 5 degree Curve Entry at 45 mph.



HI CUBE 2000: Lead Axle
Leading Truck

Base: Lead Axle
Leading Truck

Figure 7.17: High Rail Vertical Load Time Traces for the HI CUBE 2000 and Base Cars, During 5 degree Curve Entry at 45 mph.



HI CUBE 2000: Lead Axle
Leading Truck

Base: Lead Axle
Leading Truck

Figure 7.18: Low Rail Vertical Load Time Traces for the HI CUBE 2000 and Base Cars, During 5 degree Curve Entry at 45 mph.

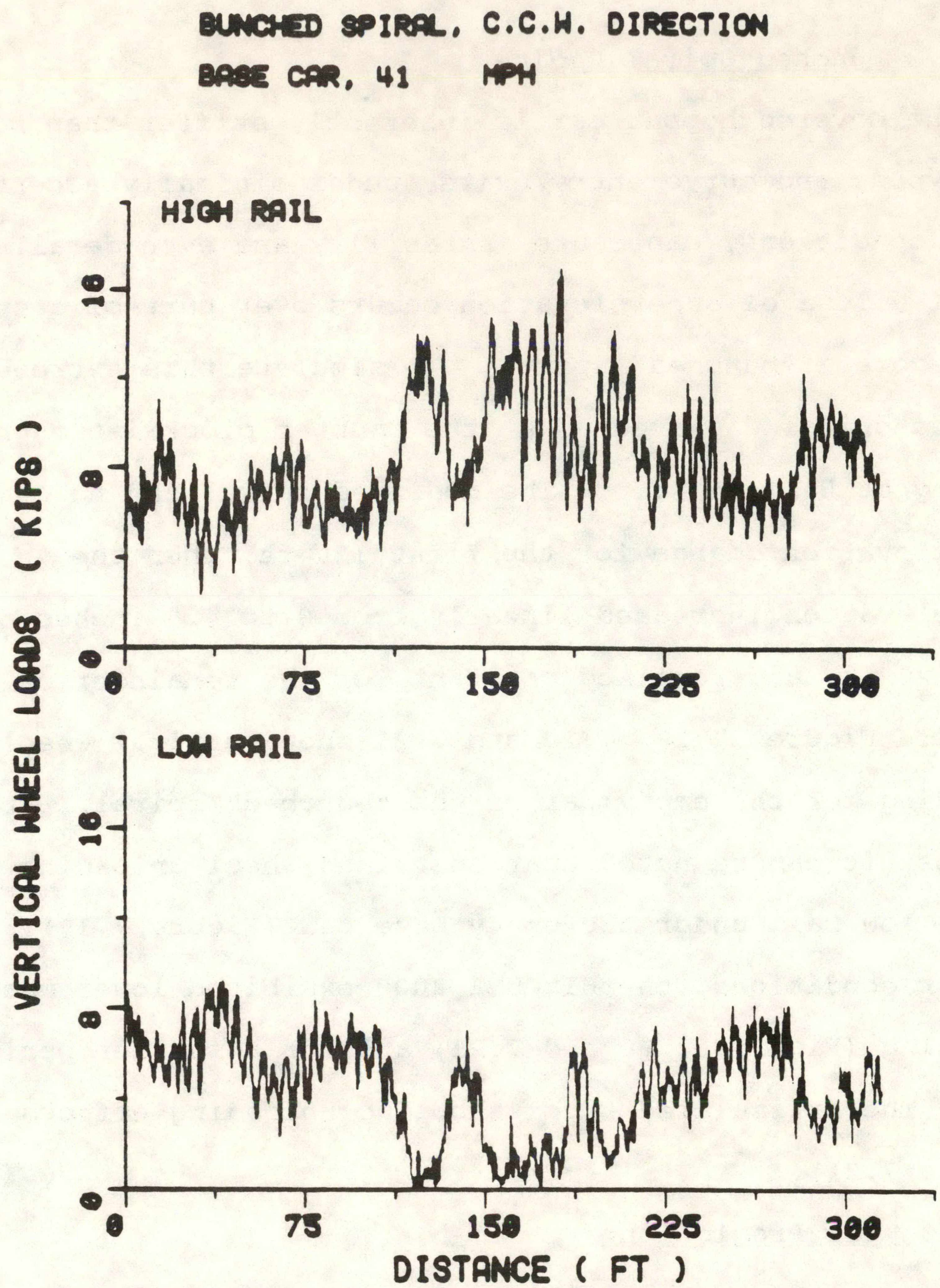
7.2 Bunched Spiral Regime

The covered hopper car is inherently stiffer than most other car types, and curve entry/exits, under minimally acceptable track conditions, can cause instability and even derailments.

If a loss of superelevation occurs over part of a spiral, it can become a "bunched" spiral. To simulate this extreme case,a bunched spiral was created at the counter clockwise entry to the 7.5 degree Balloon loop. The modified spiral had no superelevation change for the first 120 ft, then the superelevation increased linearly from 0 to 4.5 inches over the next 120 ft, and remained constant for the remainder of the spiral. Figures 7.19, 7.20 and 7.21 show vertical wheel unloading for the empty car on the "bunched" spiral. From these figures, it can be noted that sustained wheel unloading occurred at the low rail under the empty base car (Figure 7.19). Under similar conditions, the HI CUBE 2000 exhibited lower wheel unloading (Figures 7.20 and 7.21) and for a shorter period of time. The articulated truck shows no unloading effects at all (Figure 7.21).

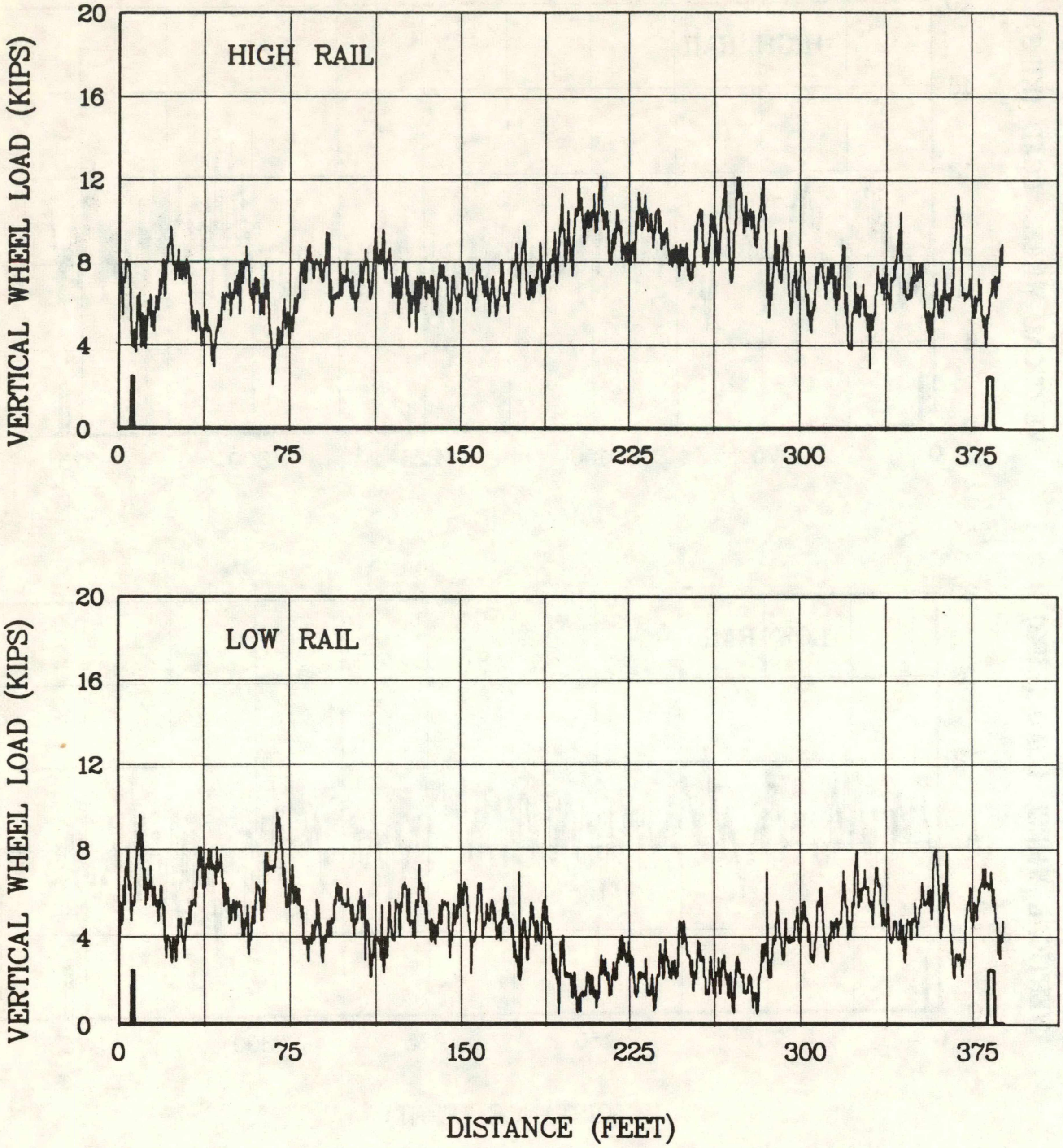
7.3 Wear Predictions

A very important curving performance parameter for a truck is wheel wear and associated rail wear during curve negotiation as well as the resistance to forward motion in curves. To be able to compare this aspect of the performance of the two cars, it is common to use nonlinear steady-state curving models of the type



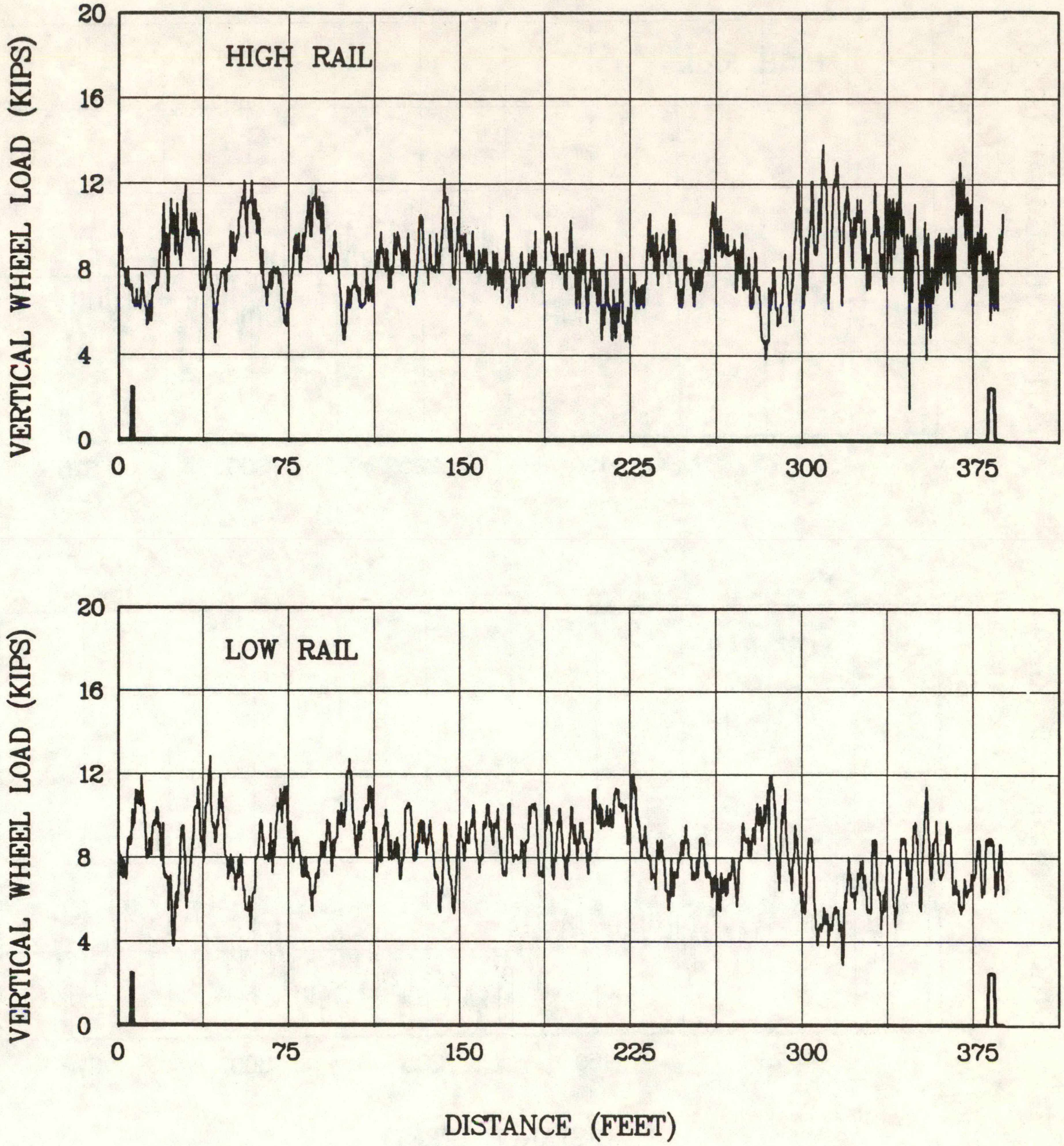
CCW at 41 mph. Lead Axle of Lead Truck

Figure 7.19: Base Car Vertical Load Time Traces at 41 mph for the Bunched Spiral Test Regime.



CCW at 35 mph Leading Axle of Leading Truck

Figure 7.20: HI CUBE 2000 Vertical Load Time Traces at 35 mph for Bunched Spiral Regime.



CCW at 35 mph Leading Axle of Articulated Truck.

Figure 7.21: HI CUBE 2000 Vertical Load Time Traces at 35 mph for Bunched Spiral Regime.

described in reference [8]. The model uses the measured wheel/rail geometrical characteristics, Kalker's creepage/creep force table and vehicle parameters to predict the loads at their wheel/rail interface and the wear index. The wear index is defined as the summation of the creep forces multiplied by the respective creepages [9], and represents the energy dissipated in the wheel/rail contact patch. This energy results in both wheel/rail wear and curving resistance.

A model [11] was used to predict the mean lateral load and the angle-of-attack for curves ranging from 1 degree to 10 degrees. Test data presented earlier showing mean lateral load <u>versus</u> curvature, for clockwise runs is used for comparing model predictions with test data. Similarly, the angle-of-attack test results are compared with model predictions. These comparisons are shown in Figures 7.22 thru 7.25.

In view of the agreement between the model predictions and test results, the model can be used to predict the wear index values. The model can provide wear index predictions for each of the two cars, for each truck, as a function of curvature, assuming a wheel/rail coefficient of friction of 0.4.

A Wear Index was calculated using the Model [11] to compare the equivalent wear index of the articulated (100-ton equivalent load) truck and the leading and trailing (70-ton equivalent load) trucks in relation to the 100-ton base car (100-ton trucks). This Wear Index comparison, shown in Figure 7.26, is based on model predictions. Figure 7.26 shows that wheel/rail wear should be about the same on the HI CUBE 2000 and the base car.

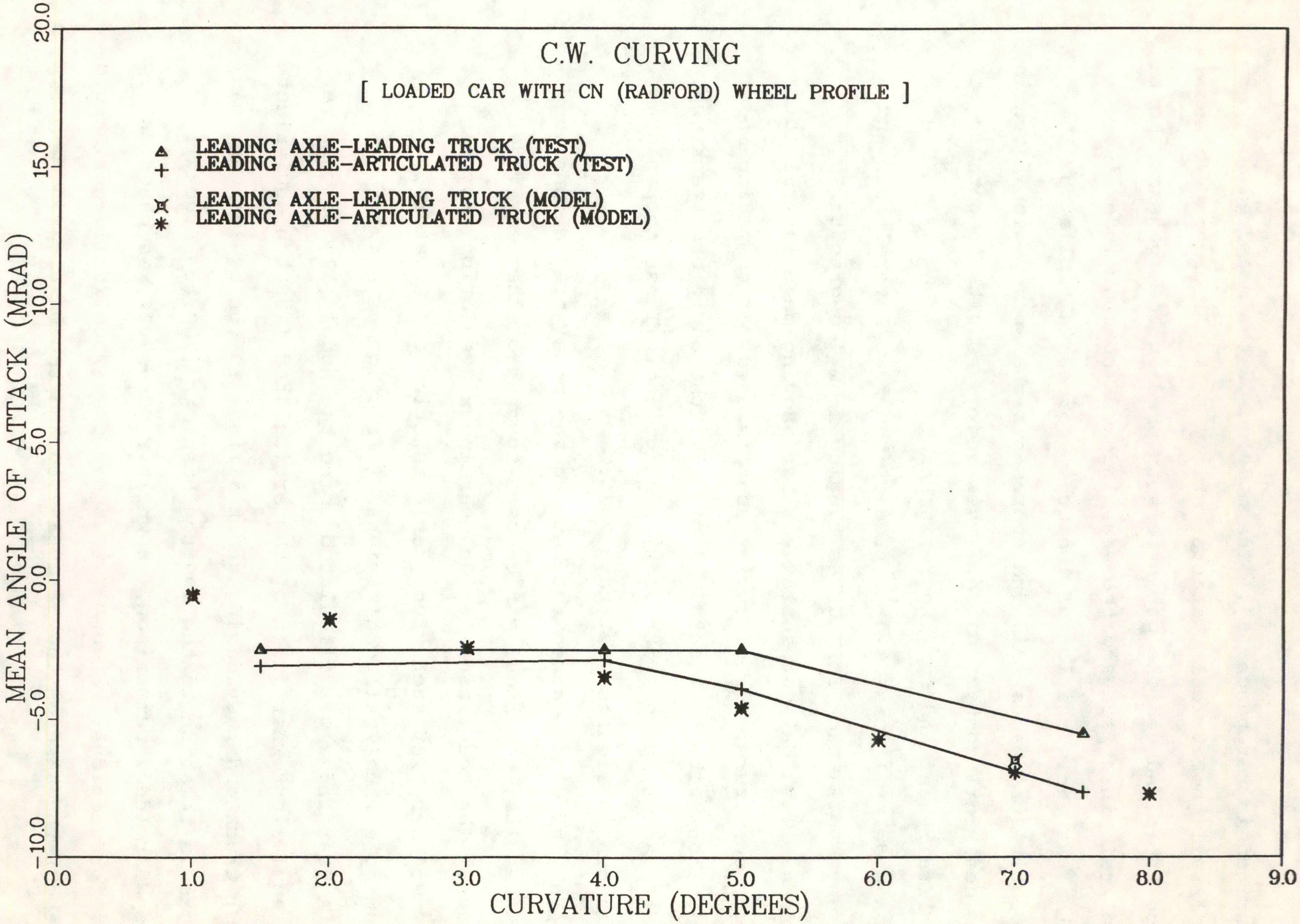


Figure 7.22: Comparing Model Predictions with Test Data for Mean Lateral Load <u>versus</u> Curvature, HI CUBE 2000, Lead Truck (70-Ton) Lead Axle.

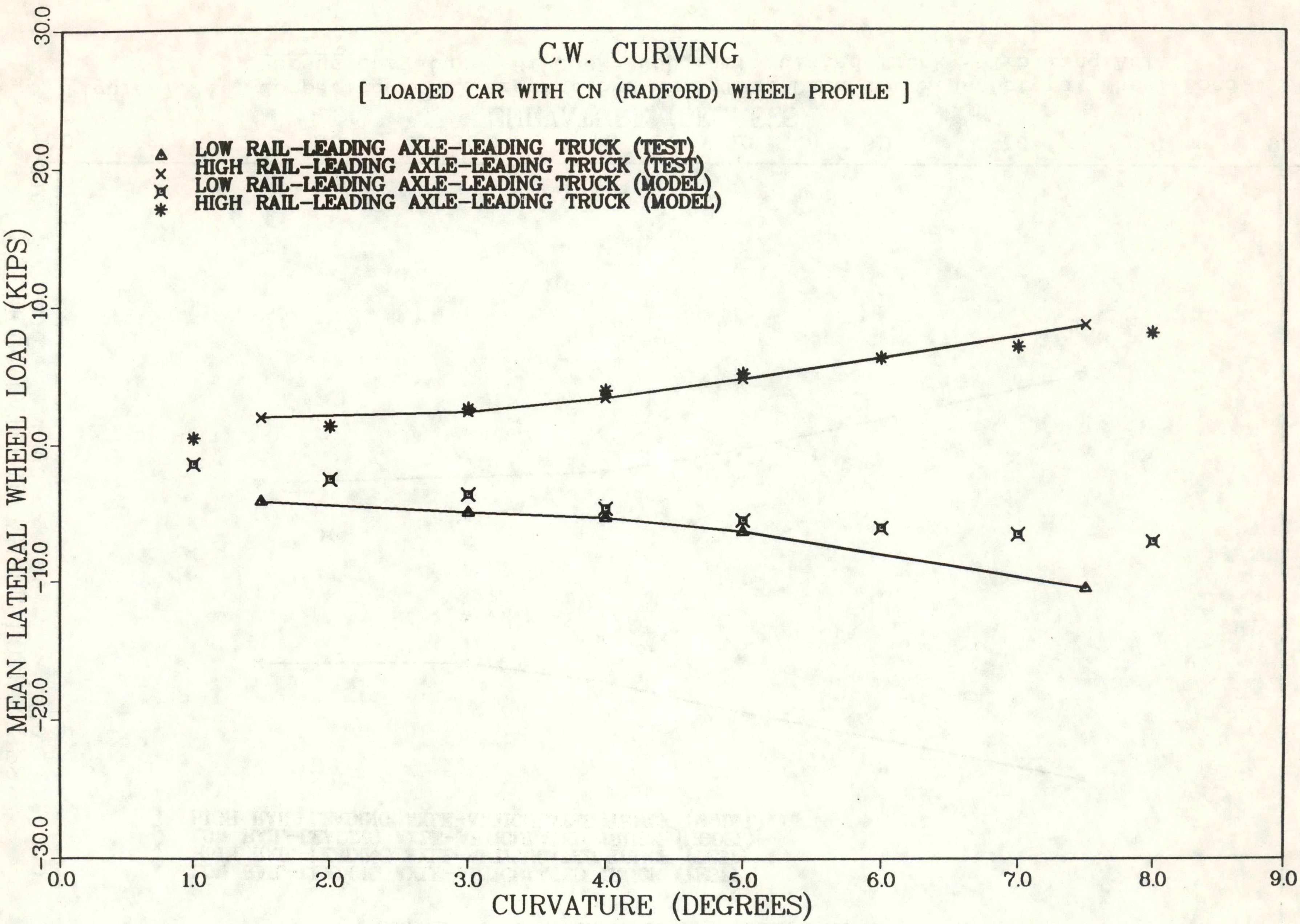


Figure 7.23: Comparing Model Predictions with Test Data for Mean Lateral Load <u>versus</u> Curvature, HI CUBE 2000, Articulated Truck (100-Ton) Lead Axle.

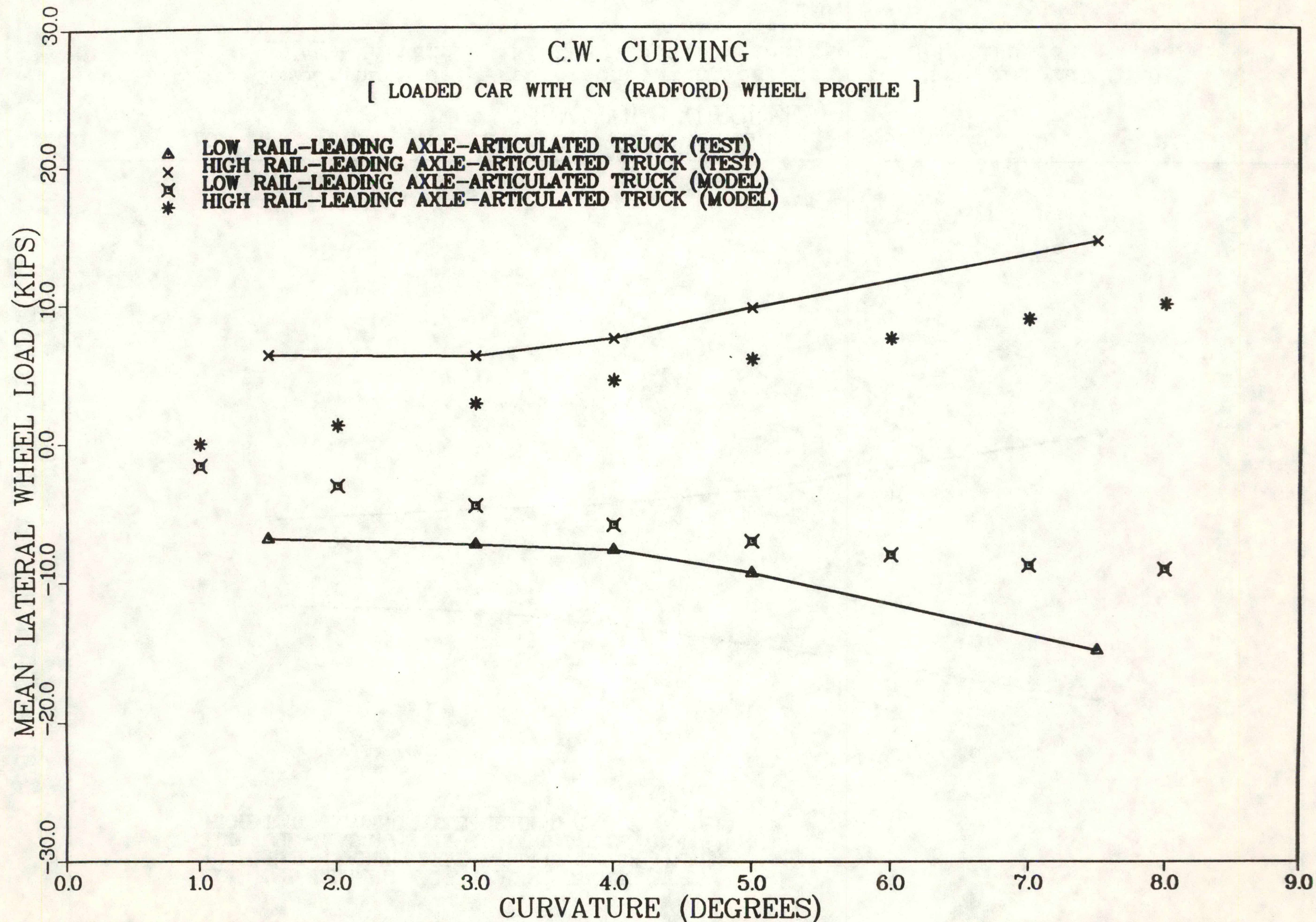


Figure 7.24: Comparing Model Predictions with Test Data for Mean Lateral Wheel Load versus Curvature, HI CUBE 2000, Articulated Truck - Trailing Axle.

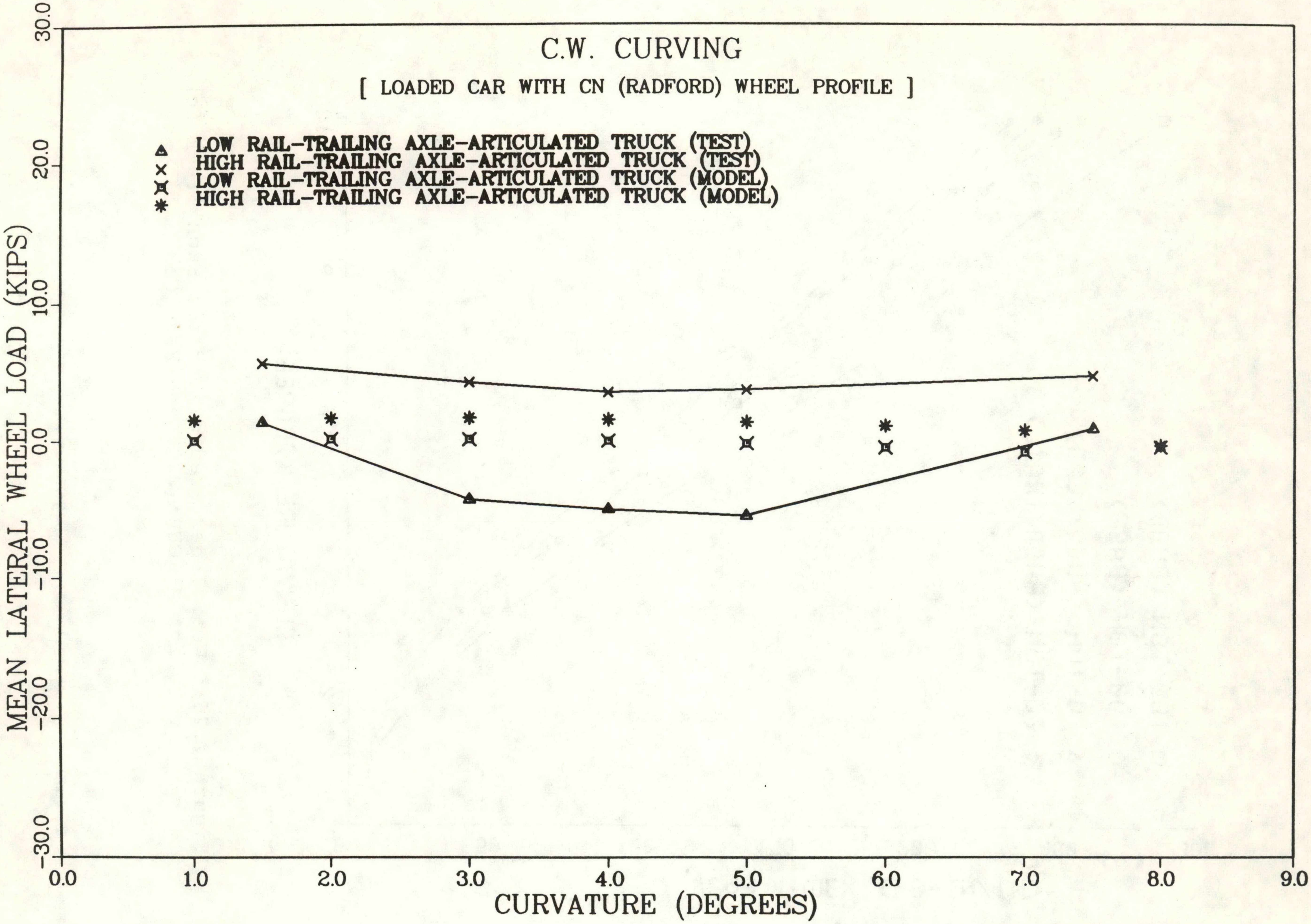


Figure 7.25: Comparing Model Predictions with Test Data for Mean Angle-of-Attack <u>versus</u> Curvature, HI CUBE 2000.

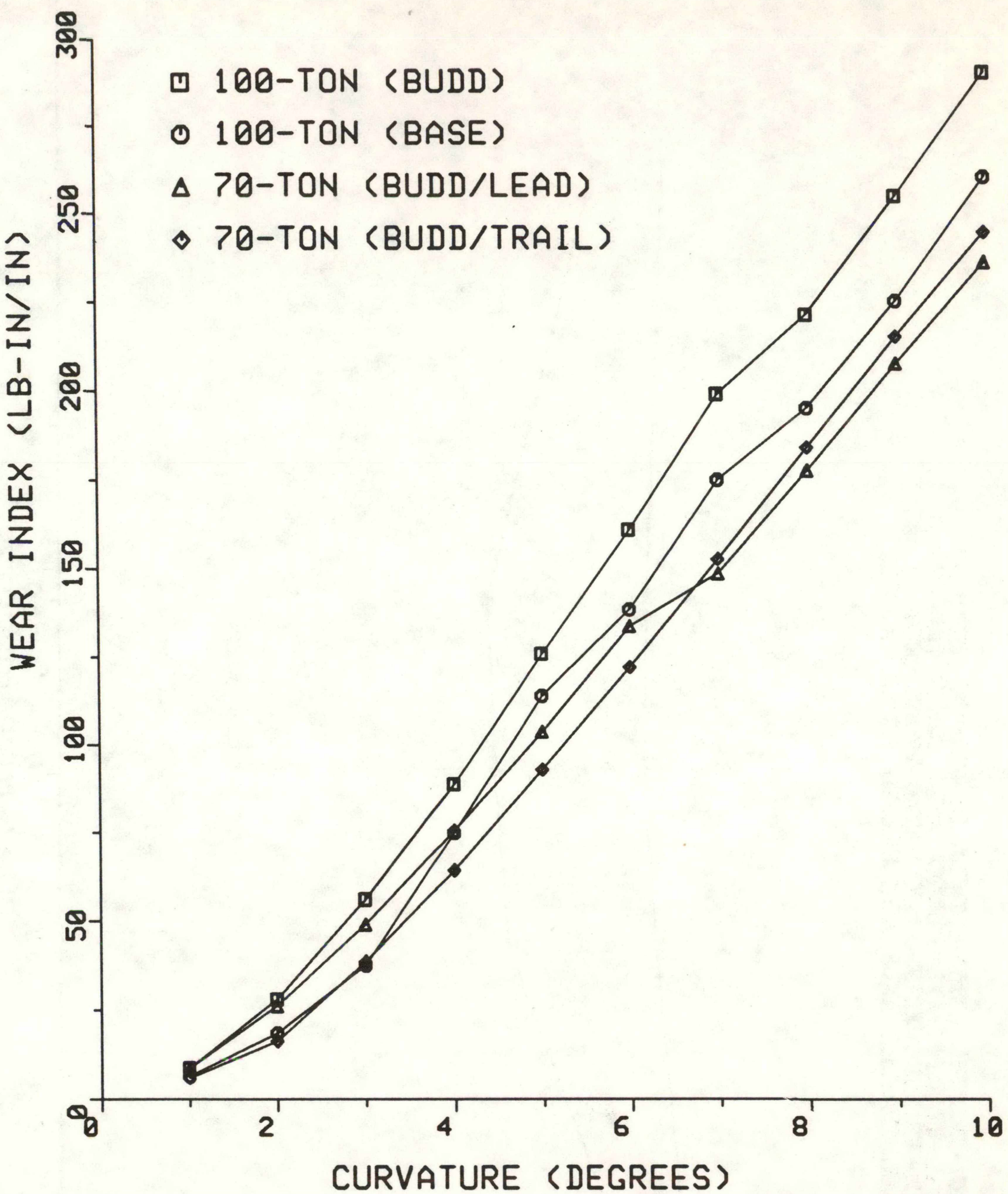


Figure 7.26: Wear Index Predictions for Each Truck for for HI CUBE 2000 and Base Car.

8.0 CONCLUSIONS

The results of a dynamic performance evaluation of a prototype high-cube covered hopper car, the Transit America HI CUBE 2000, in comparison with a current design, the base car, have been summarized for different dynamic performance regimes.

The dynamic performance of the HI CUBE 2000 as compared with the base car are presented at the end of each section. The HI CUBE 2000, performed better than the base car in most of the test regimes, as summarized below:

a) Rock-and-roll: lower peak-to-peak carbody roll angles and less wheel unloading.

b) Pitch-and-bounce: lower acceleration levels and less wheel unloading.

c) Hunting: lower acceleration levels and higher critical speed.

d) Curving: comparable lateral wheel loads.

e) Curve entry/exit: comparable performance against base car.

f) Bunched spiral: less wheel unloading for a shorter period of time. No unloading on articulated truck.

g) Wear prediction: no significant increase in wheel/rail wear and curving resistance.

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