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Final Report

Contract FH-11-7290

March 1971

BUS, TRUCK, TRACTOR-TRAILER BRAKING SYSTEM PERFORMANCE

Volume 2 of 2: Appendixes and References

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16. Abstract

The objectives of this study were to determine the range of braking performance currently exhibited by buses, trucks, and tractor-trailers and to establish the maximum braking performance capabilities of these vehicles based upon full utilization of the technology related to brake system design. Both vehicle testing and analytical techniques, including dynamic modeling and simulation, were used to accomplish these objectives. Performance measures were defined which serve to quantify the degree to which a given vehicle-braking system possesses those qualities necessary for adequate braking performance. Using these measures, a braking performance standard is recommended based upon a comparative analysis of (1) current braking performance, (2) the maximum performance achievable by full exploitation of existing technology, and (3) performance as constrained by a host of associated factors.

17. Key Words

brake performance, brakes, brake systems, trucks, buses, tractor-trailers

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Appendix A

TEST VEHICLES: DATA AND SPECIFICATIONS

Provided in this appendix are specifications for each vehicle tested, along with data on the brake system, tires, and load configurations.

The table of specifications includes: type of vehicle, make, model, year, identification number, engine, transmission, and rear axle data, size and type of tires, size and type of brakes and brake linings, and type of emergency and parking brakes.

The loading diagram contains axle loading information and dimensions such as wheel base and load center of gravity location. For combination vehicles, dimensions are given on trailer length, fifth wheel location, and location of the trailer axle(s) relative to the tractor.

A brake system schematic is given for each vehicle (except for Vehicle 14), detailing line lengths and sizes, connector locations, and wheel cylinder or brake chamber sizes.

A.1 Trucks

A.1.1 VEHICLE SPECIFICATIONS

Vehicle: Light Truck Type: 2-axle van
Make: Chevrolet Model: C30 Year: 1969
Identification Number: CE 339F854065
Engine: 307 V8-200 HP Gas
Transmission: Standard 3-speed Rear Axle: Standard

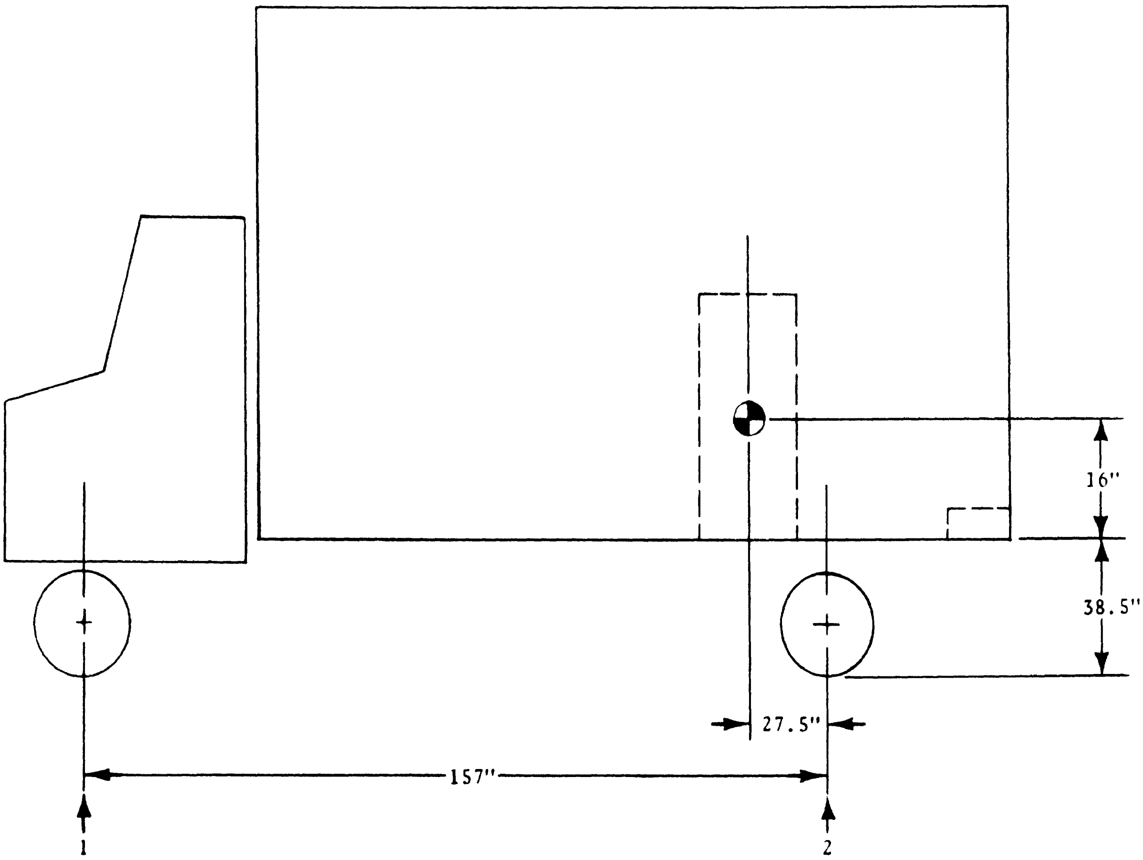
Tires	Manufacturer	Size	Tire Pressure, psi
Front Axle	Goodrich	7:50 x 16	50
Rear Axle	Goodrich	7:50 x 16 Duals	50

Brakes	Manufacturer	Size	Type
Front Axle	Delco	11-1/8 x 2-3/4	Duo-Servo
Rear Axle	Delco	13 x 2-1/2	Duo-Servo

Brake Linings	Manufacturer	Type
Front Axle	General Motors	218 FF/208GH
Rear Axle	General Motors	218 FF/208GH

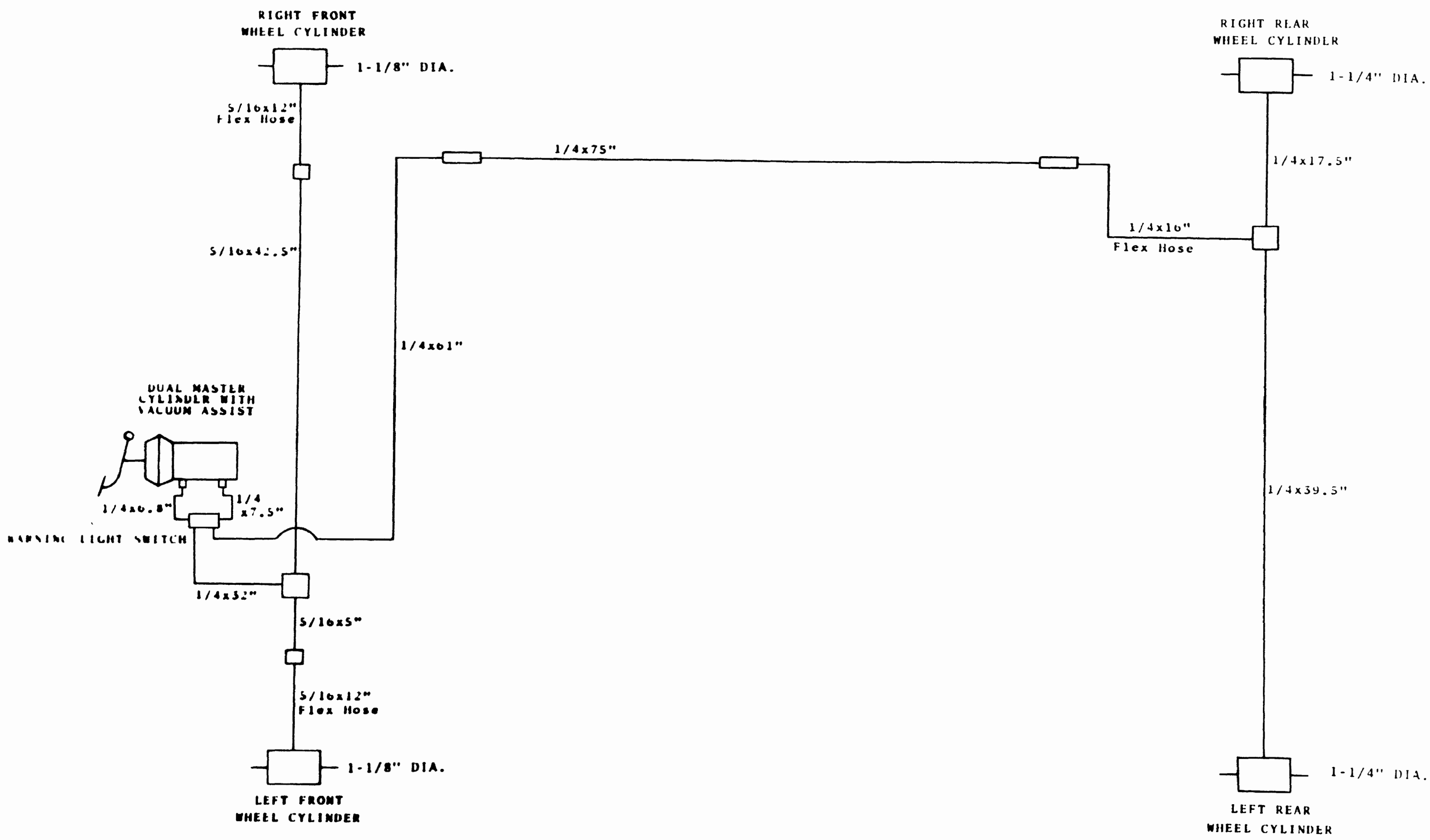
Brake System: Hydraulic, vacuum assist, dual circuit

Emergency/Parking Brake: Hand lever, mechanical actuation of rear brakes



AXLE	1	2	TOTAL
EMPTY	2,811	3,953	6,764
LOADED	3,502	7,230	10,732

A.1.2 LOADING DIAGRAM, LIGHT TRUCK: CHEVROLET C-30 VAN



A.1.3 BRAKE SYSTEM SCHEMATIC, LIGHT TRUCK: CHEVROLET C-30 VAN

A.1.4 VEHICLE SPECIFICATIONS

Vehicle: Medium Truck Type: 2-axle flatbed
Make: IHC Model: CO-1700 Year: 1969
Identification Number: 426700C036102
Engine: V 345 8-Cyl. Gas
Transmission: T36 5-speed direct Rear Axle: 650/887

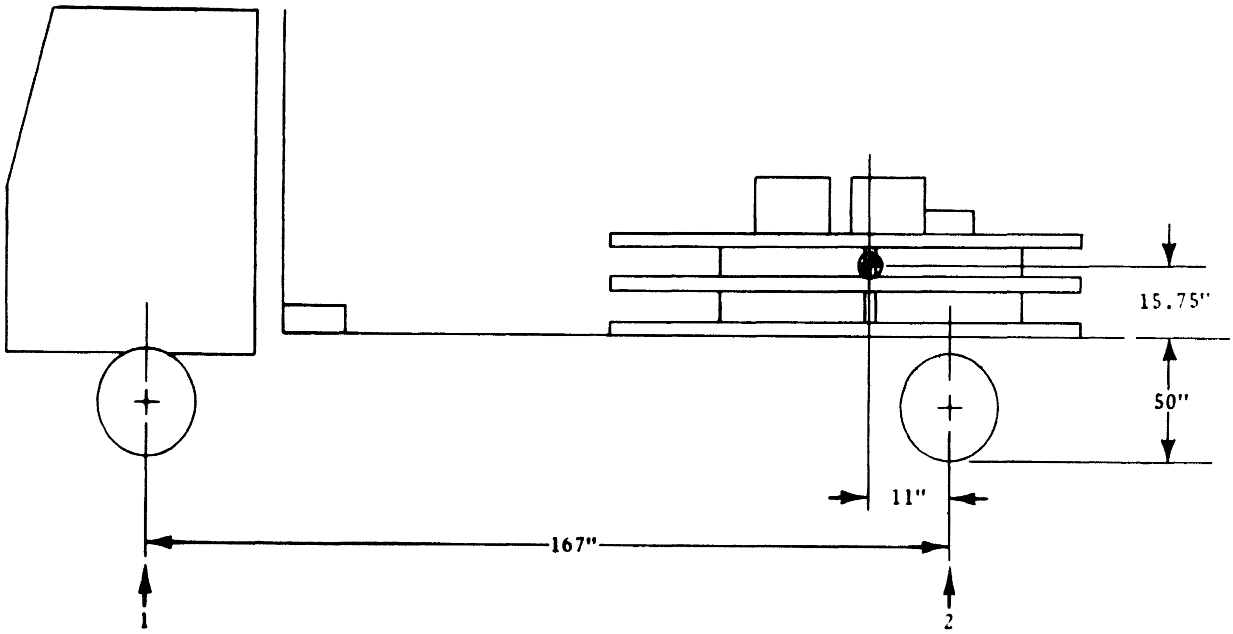
Tires	Manufacturer	Size	Tire Pressure, psi
Front Axle	Goodyear	10 x 20	75
Rear Axle	Goodyear	10 x 20 Duals	85

Brakes	Manufacturer	Size	Type
Front Axle	Wagner	15 x 3	Two leading shoe
Rear Axle	Wagner	16 x 6	Twinplex

Brake Linings	Manufacturer	Type
Front Axle	ABB	693-551-D
Rear Axle	ABB	693-539

Brake System: Vacuum-hydraulic

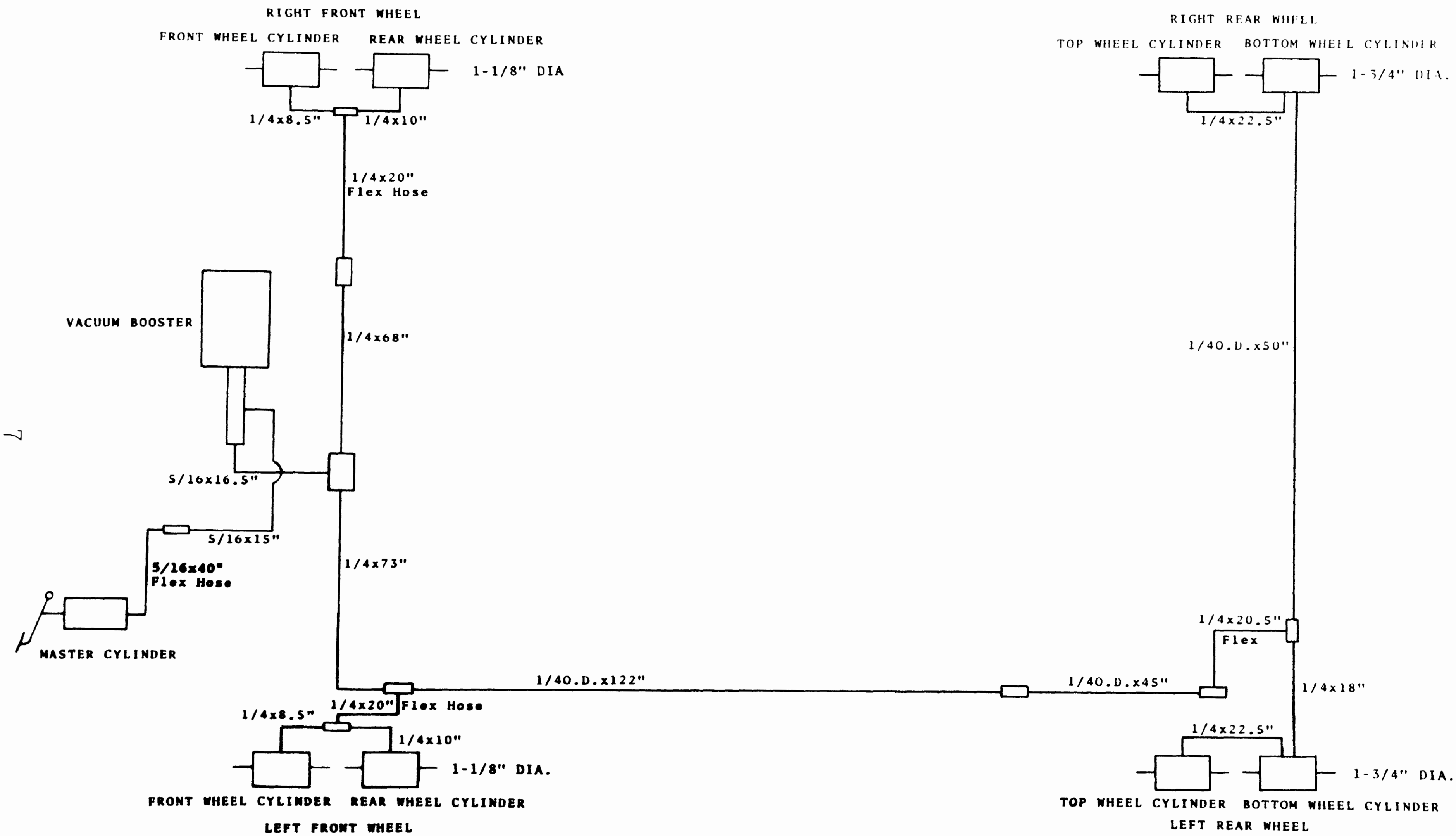
Emergency/Parking Brake: Hand-operated, mechanical actuation to drive shaft brake



AXLE	1	2	TOTAL
EMPTY	6,340	4,580	10,920
LOADED	7,490	18,010	25,500

LOAD C.G.

A.1.5 LOADING DIAGRAM, MEDIUM TRUCK: IHC CO-1700 18-FT FLATBED



A.1.6 BRAKE SYSTEM SCHEMATIC, MEDIUM TRUCK: IHC CO-1700 18-FT FLATBED

A.1.7 VEHICLE SPECIFICATIONS

Vehicle: Heavy Truck Type: 3-axle dump
Make: Chevrolet Model: J70 Year: 1968
Identification Number: JM7140P106620
Engine: 401V6
Transmission: SP652 Rear Axle: E30D SC

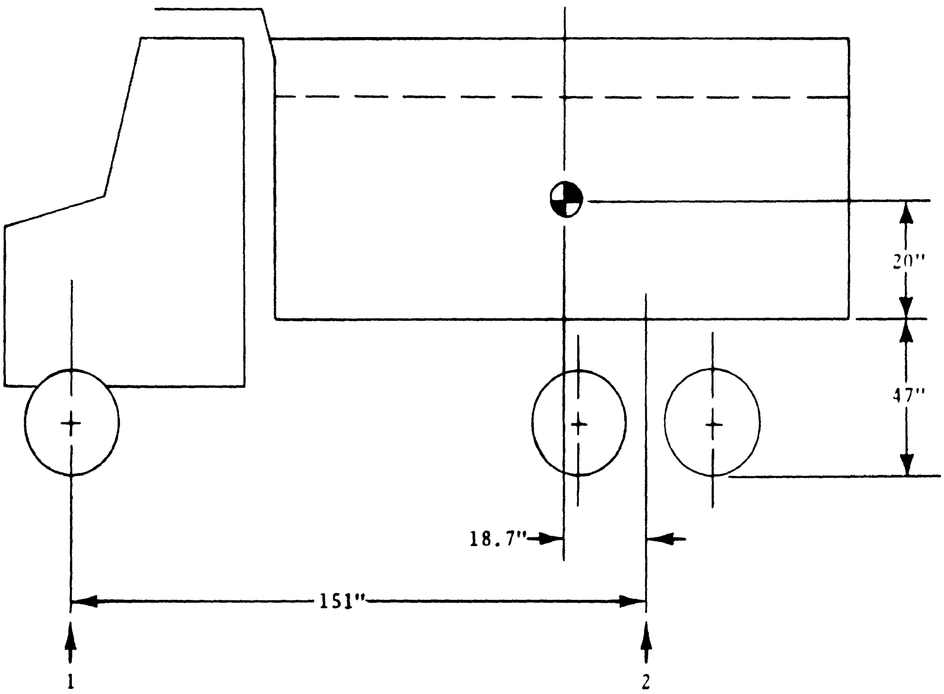
Tires	Manufacturer	Size	Tire Pressure, psi
Front Axle	Firestone	9.00 x 20	85
Rear Axle	Firestone	9.00 x 20 Dual	70
Tandem Axle	Firestone	9.00 x 20 Dual	70

Brakes	Manufacturer	Size	Type
Front Axle	Wagner	15 x 3-1/2	S-Cam
Rear Axle	Rockwell	15 x 5	Wedge
Tandem Axle	Rockwell	15 x 5	Wedge

Brake Linings	Manufacturer	Type
Front Axle	ABB	639-551C
Rear Axle	ABB	639-539
Tandem Axle	ABB	639-539

Brake System: Air

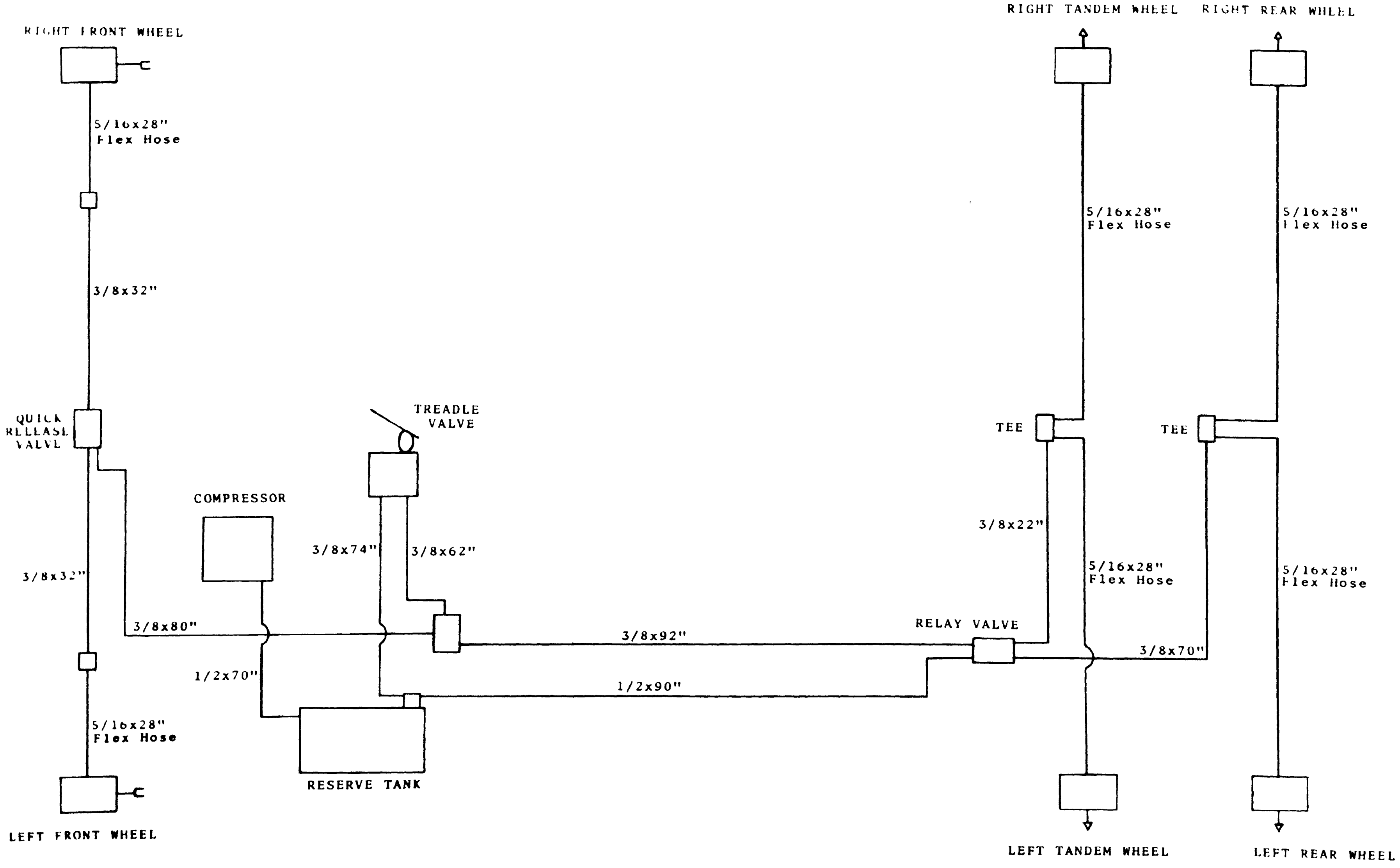
Emergency/Parking Brake: Hand-operated, mechanical actuation on drive shaft



AXLE	1	2	TOTAL
EMPTY	6,100	9,500	15,600
LOADED	9,000	30,000	39,000

LOAD C.G.

A.1.8 LOADING DIAGRAM, HEAVY TRUCK: CHEVROLET J-70 DUMP TRUCK



A.1.9 BRAKE SYSTEM SCHEMATIC, HEAVY TRUCK: CHEVROLET J-70 DUMP TRUCK (6x4)

A.2 Buses

A.2.1 VEHICLE SPECIFICATIONS

Vehicle: School Bus Type: 66 passenger (2-axle)
Make: Ford Model: B750 Year: 1969
Identification Number: B75EVE4600
Engine: 361HDV-8 210HP
Transmission: 285 V-5 speed Rear Axle: Single speed 6.80-1

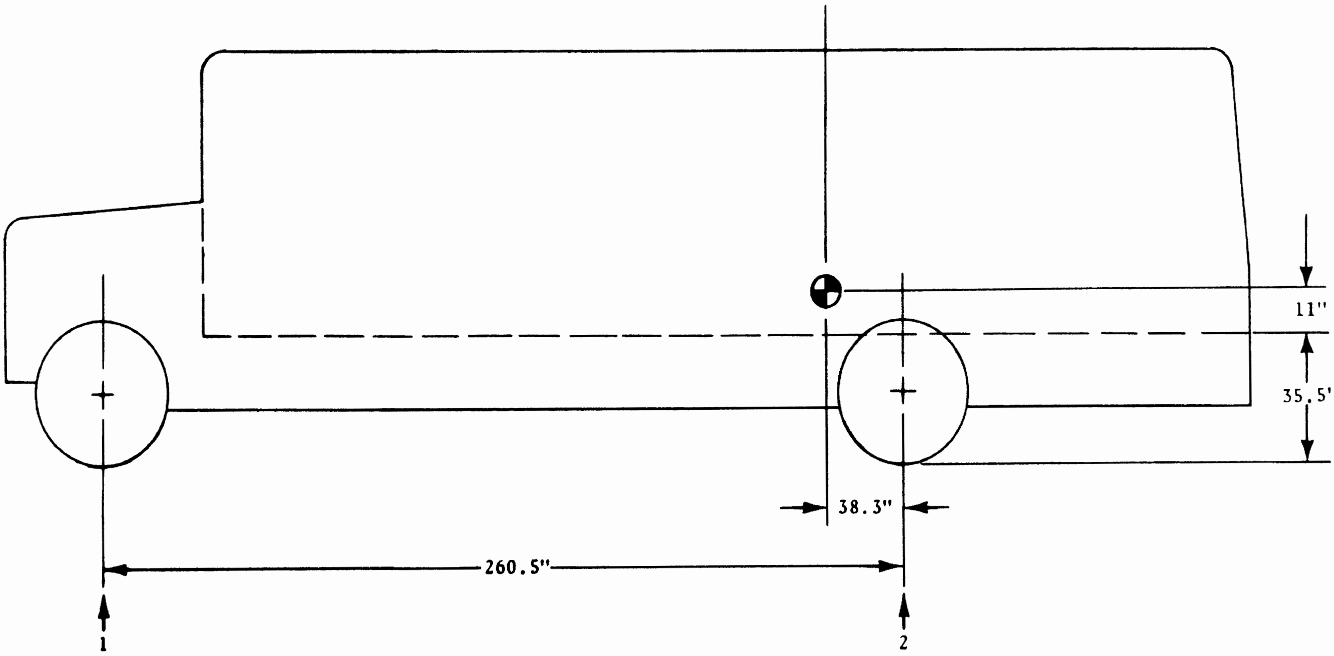
Tires	Manufacturer	Size	Tire Pressure, psi
Front Axle	Firestone	9.00 x 20	55
Rear Axle	Firestone	9.00 x 20 Dual	85

Brakes	Manufacturer	Size	Type
Front Axle	Bendix	15 x 3	Wedge
Rear Axle	Bendix	15 x 5	Wedge

Brake Linings	Manufacturer	Type
Front Axle	Raybestos	RM4715/ME90516
Rear Axle	ABB	693-551D

Brake System: Air

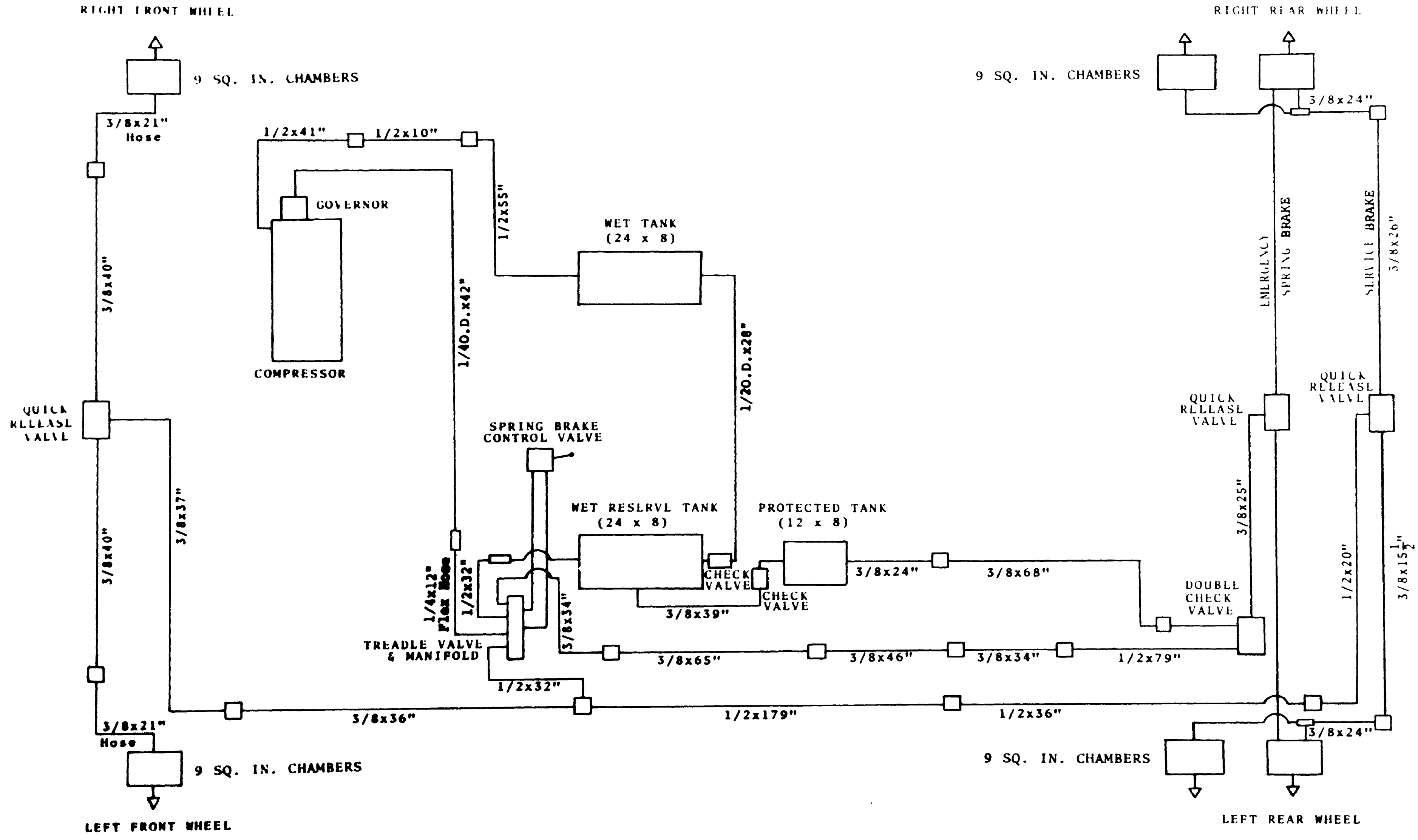
Emergency/Parking Brake: Modulated spring brakes on rear wheels



AXLE	1	2	TOTAL
EMPTY	5,470	8,580	14,050
LOADED	7,000	17,500	24,500

LOAD C.G.

A.2.2 LOADING DIAGRAM: FORD 750 SCHOOL BUS



A.2.3 BRAKE SYSTEM SCHEMATIC: FORD 750 SCHOOL BUS

A.2.4 VEHICLE SPECIFICATIONS

Vehicle: Intercity Bus Type: Deluxe Coach
Make: Motor Coach Indus. Model: MC-7 Year: 1969
Identification Number: 7686
Engine: 8V-71N 567.5 In^3
Transmission: 4-speed Spicer Rear Axle: R163, 3.36-1

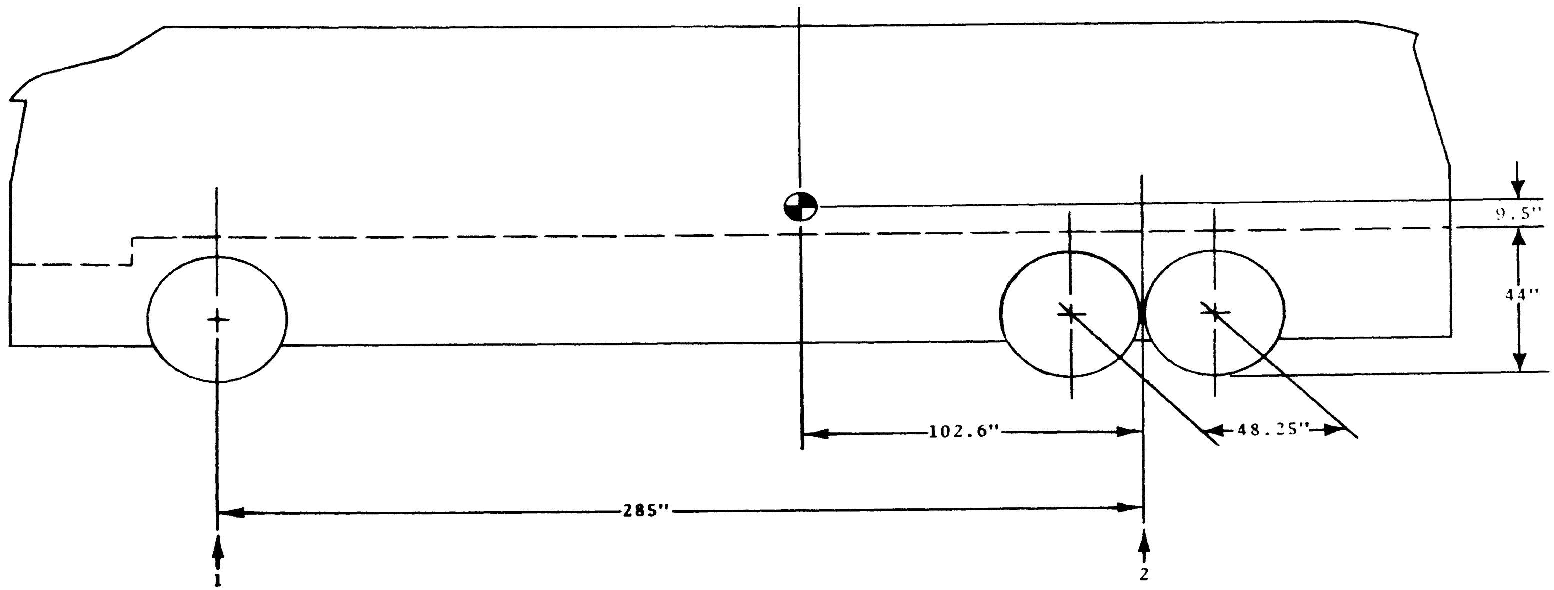
Tires	Manufacturer	Size	Tire Pressure, psi
Front Axle	Firestone	11.5 x 22.5	100
Drive Axle	Firestone	11.5 x 22.5 Dual	75
Tag Axle	Firestone	11.5 x 22.5	75

Brakes	Manufacturer	Size	Type
Front Axle	Rockwell	14.5 x 5	S-Cam
Drive Axle	Rockwell	14.5 x 8	S-Cam
Tag Axle	Rockwell	14.5 x 5	S-Cam

Brake Linings	Manufacturer	Type
Front Axle	ABB	693-551
Drive Axle	ABB	693-531
Tag Axle	ABB	693-531

Brake System: Air

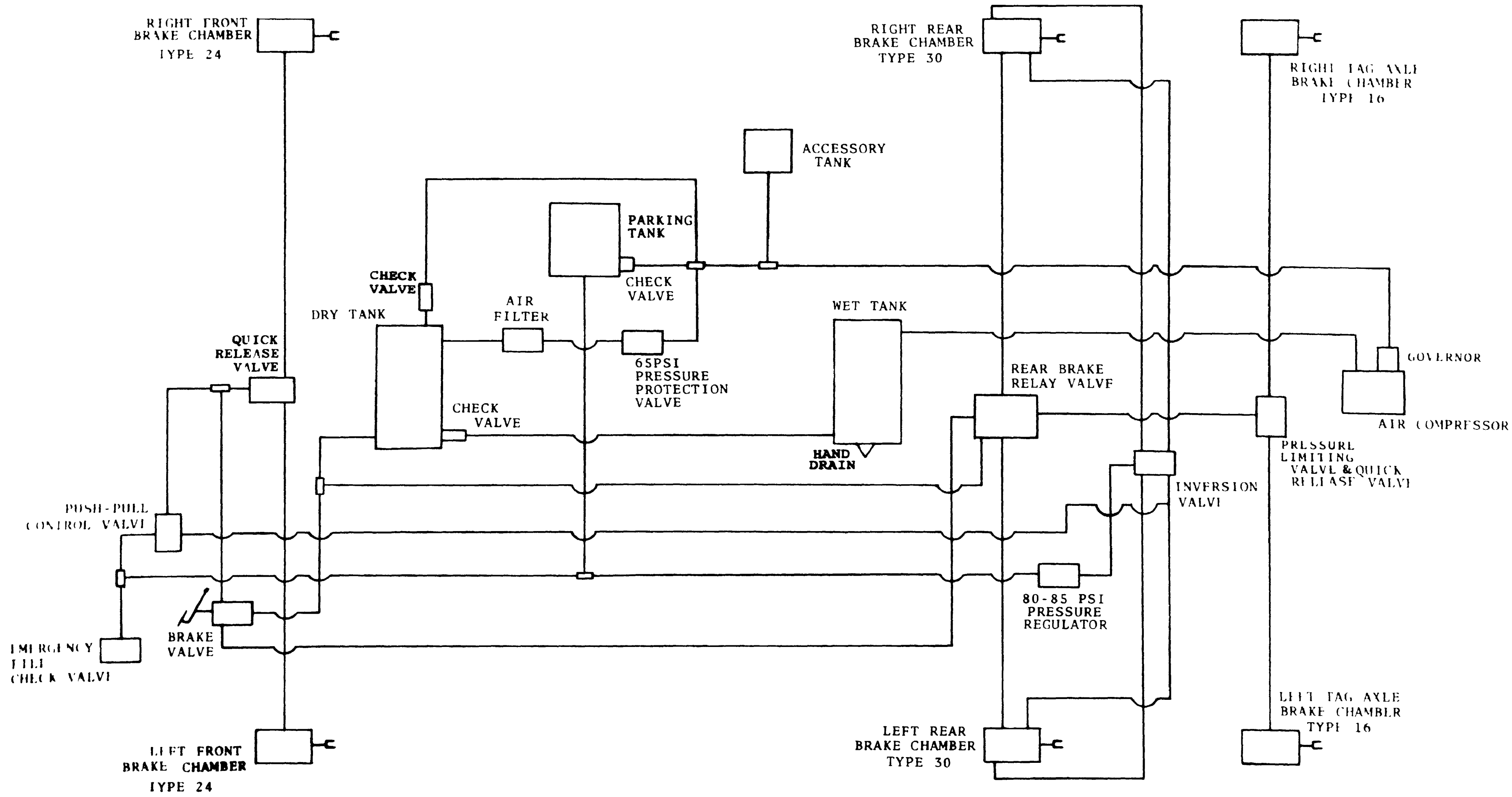
Emergency/Parking Brake: Separate actuation of rear brakes



AXLE	1	2	TOTAL
EMPTY	9,420	18,470	27,890
LOADED	12,090	23,850	35,940

LOAD C.G.

A.2.5 LOADING DIAGRAM, INTERCITY BUS: MCI MC-7 INTERCITY COACH



A.2.6 BRAKE SYSTEM SCHEMATIC: MC-7 INTERCITY COACH

A.2.7 VEHICLE SPECIFICATIONS

Vehicle: City Bus Type: 53 passenger (2-axle)
Make: GMC Model: T6H 5305 Year: 1969
Identification Number: 247
Engine: Detroit V6
Transmission: Allison Infinite Rear Axle: Rockwell 5.14

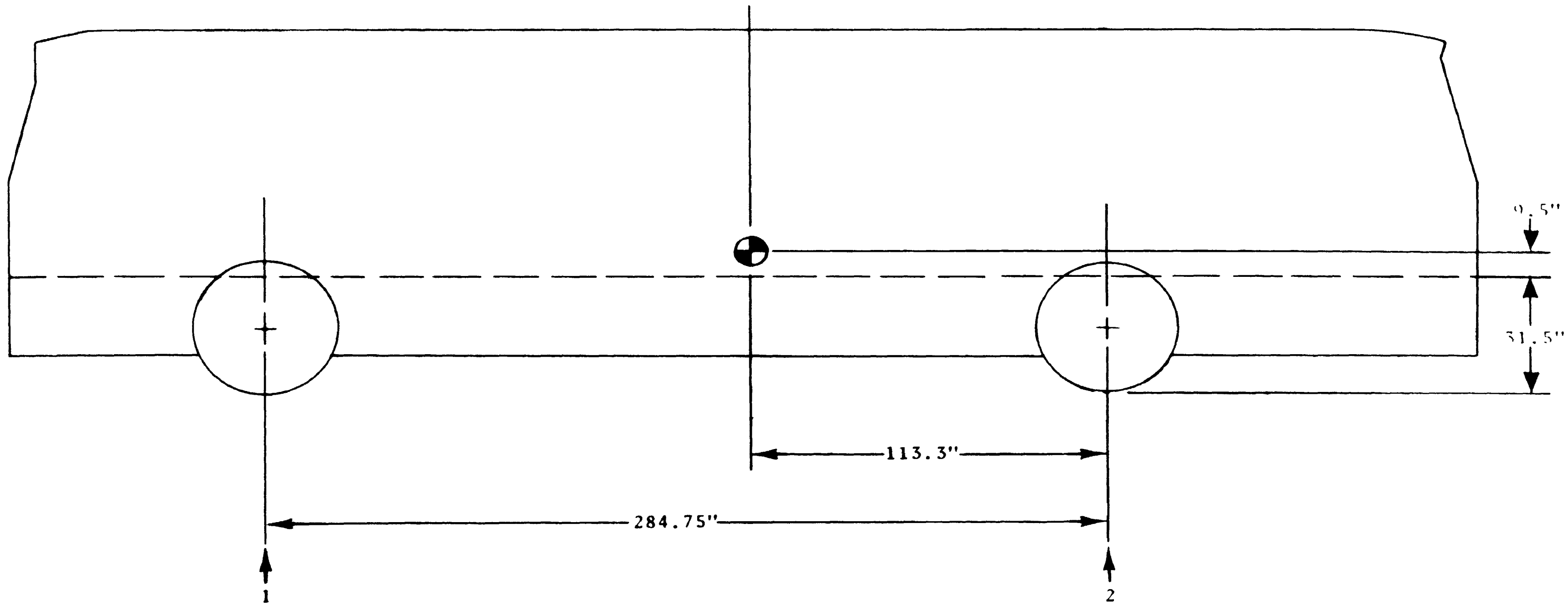
Tires	Manufacturer	Size	Tire Pressure, psi
Front Axle	Firestone	11 x 20	80
Rear Axle	Firestone	11 x 20	80

Brakes	Manufacturer	Size	Type
Front Axle	---	14.5 x 5	S-Cam
Rear Axle	---	14.5 x 10	S-Cam

Brake Linings	Manufacturer	Type
Front Axle	ABB	80(206 FF)
Rear Axle	ABB	80(206 FF)

Brake System: Air

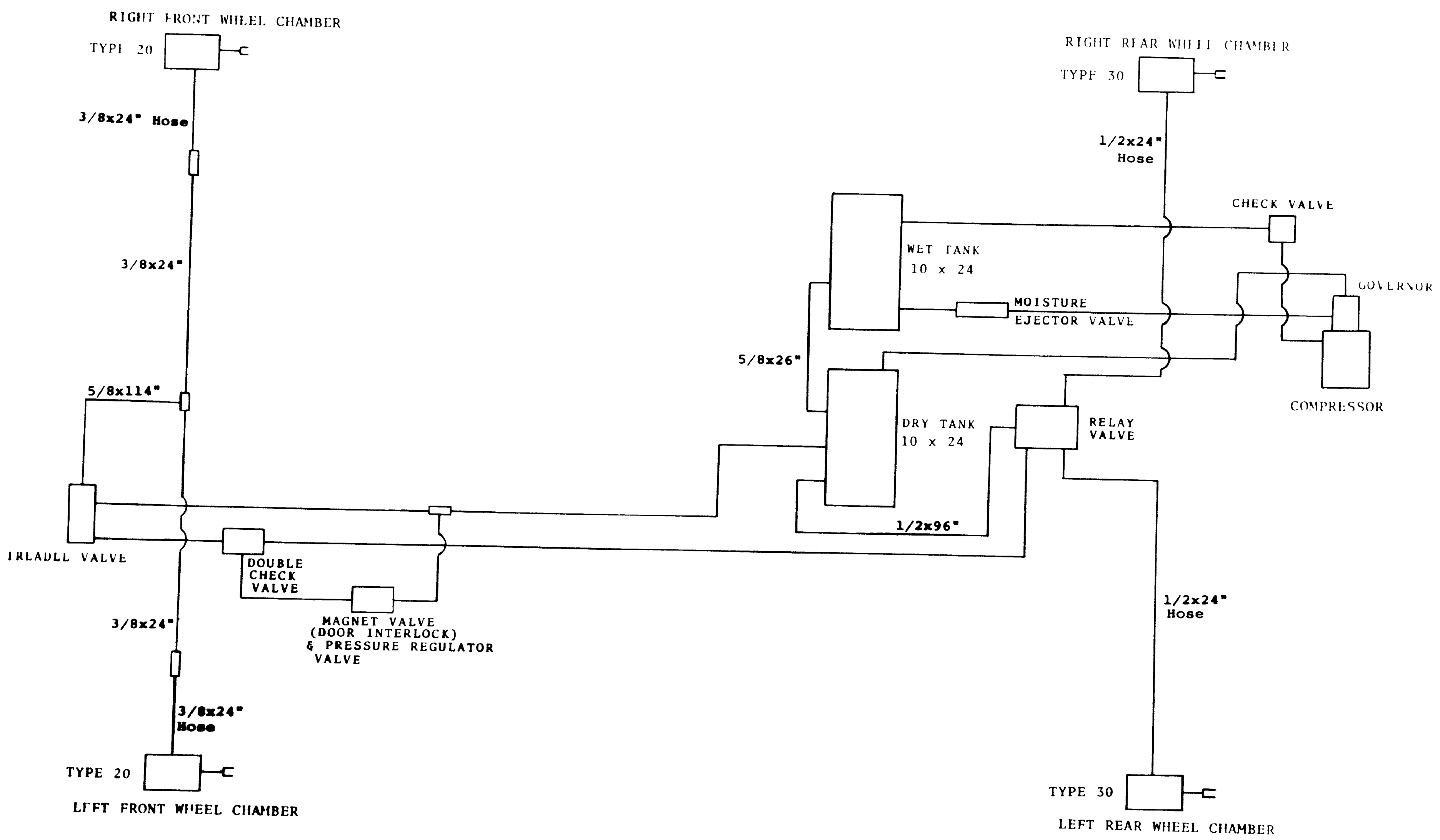
Emergency/Parking Brake: Separate actuation of rear brakes and hand-operated parking brake on drive shaft



AXLE	1	2	TOTAL
EMPTY	6,200	15,000	21,200
LOADED	10,580	21,565	32,145

LOAD C.G.

A.2.8 LOADING DIAGRAM, INTERCITY BUS: GMC T6H-5305 BUS



A.2.9 BRAKE SYSTEM SCHEMATIC: GMC—COACH

A.3 Tractor-Trailers

A.3.1 VEHICLE SPECIFICATIONS

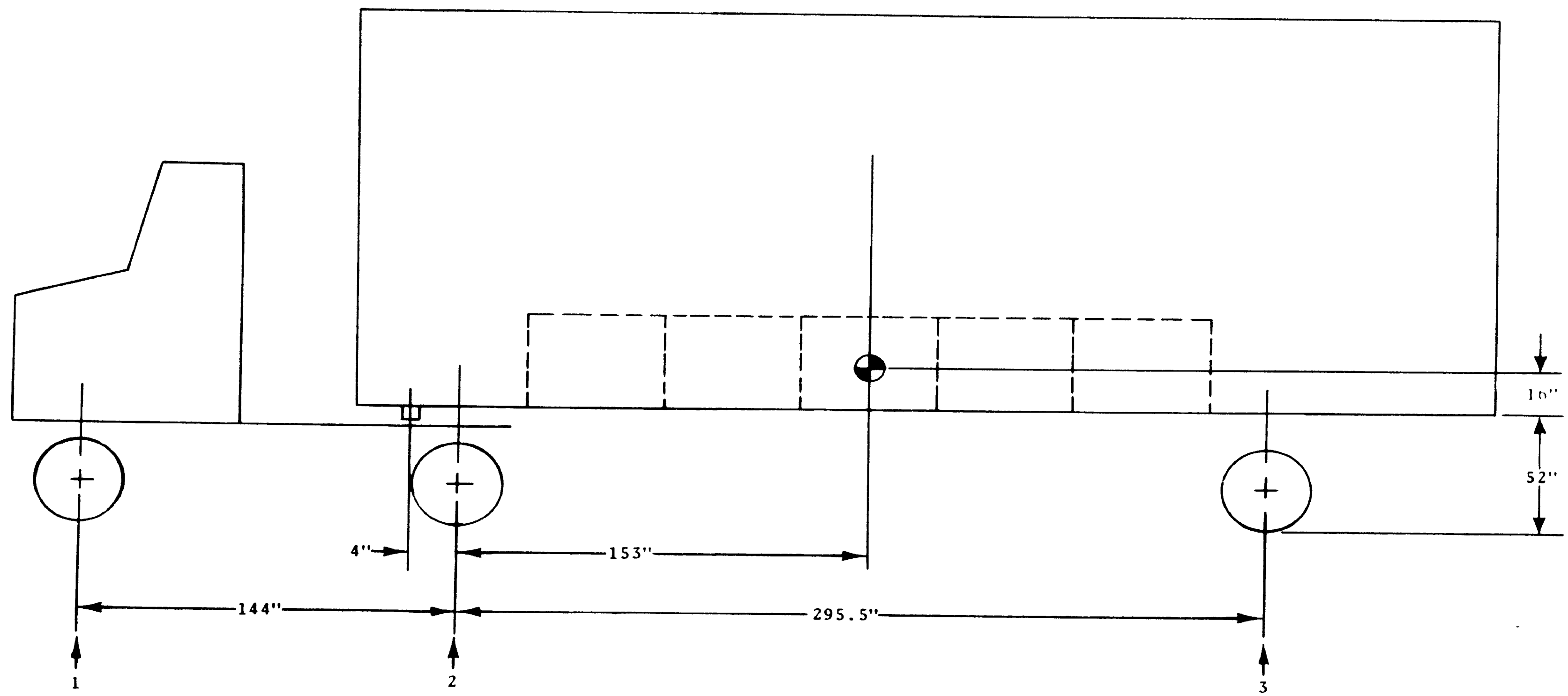
Tractor-Trailer 2-S1
Tractor Type: CBE, 2-axle
Make: Ford Model: F-7000 Year: 1970
Identification Number: K 704 UG 31185
Engine: Caterpillar V-200
Trailer Type: Van, single axle
Make: Trailmobile Model: A32DAAE Year: 1970

Tires	Manufacturer	Size	Tire Pressure, psi
Tractor Front	Firestone	10 x 20	60
Tractor Rear	Goodyear	10 x 20 Duals	75
Trailer Rear	Uniroyal	10 x 20 Duals	75

Brakes	Manufacturer	Size	Type
Tractor Front	---	16 x 2.5	S-Cam
Tractor Rear	Eaton	16.5 x 6	S-Cam
Trailer	---	16.5 x 7	S-Cam

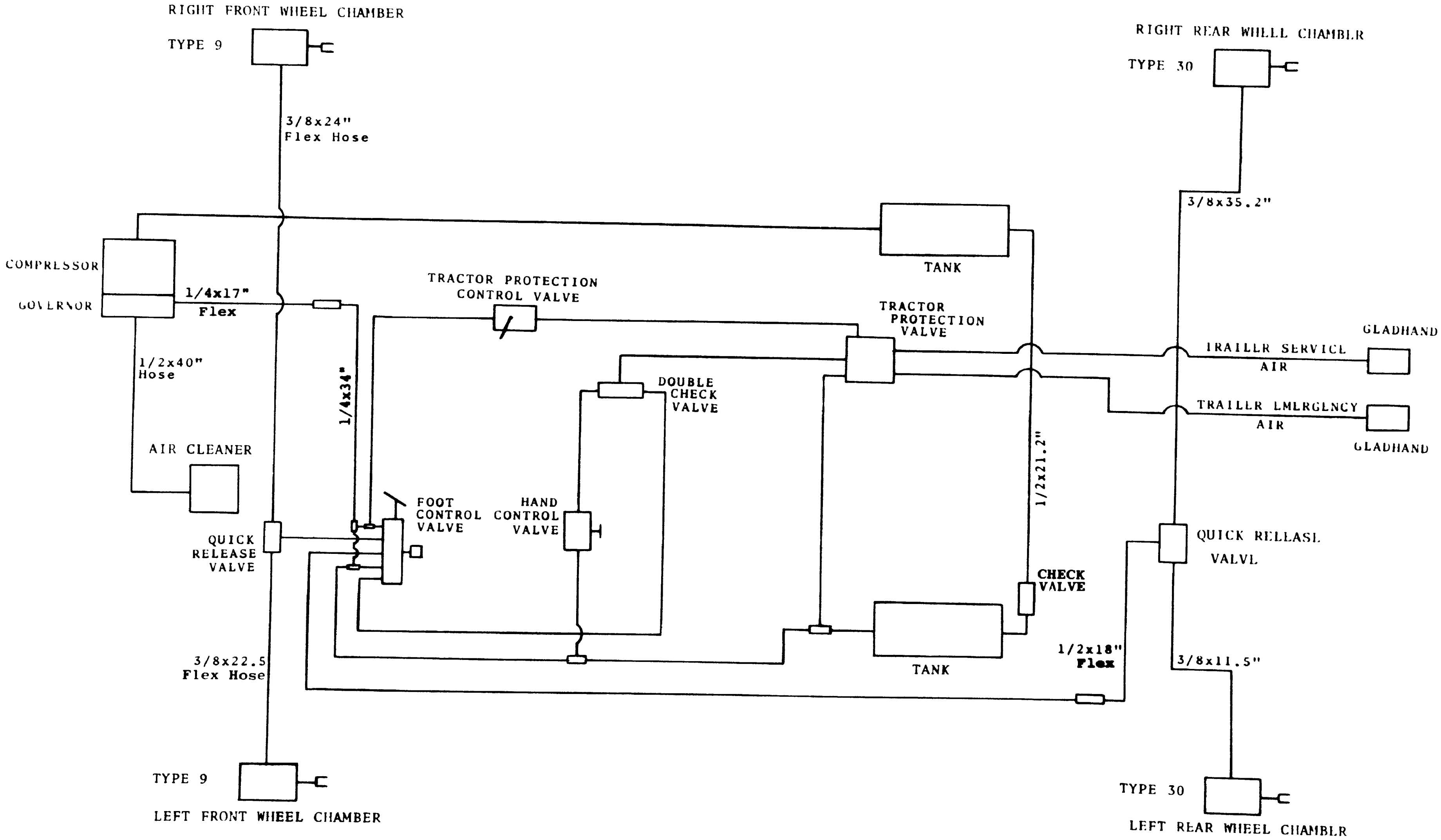
Brake Linings	Manufacturer	Type
Tractor Front	Bendix	H-3149A/H-3149
Tractor Rear	Molded Mat'ls	MMD-16
Trailer	ABB	693-551

Emergency System: Standard air

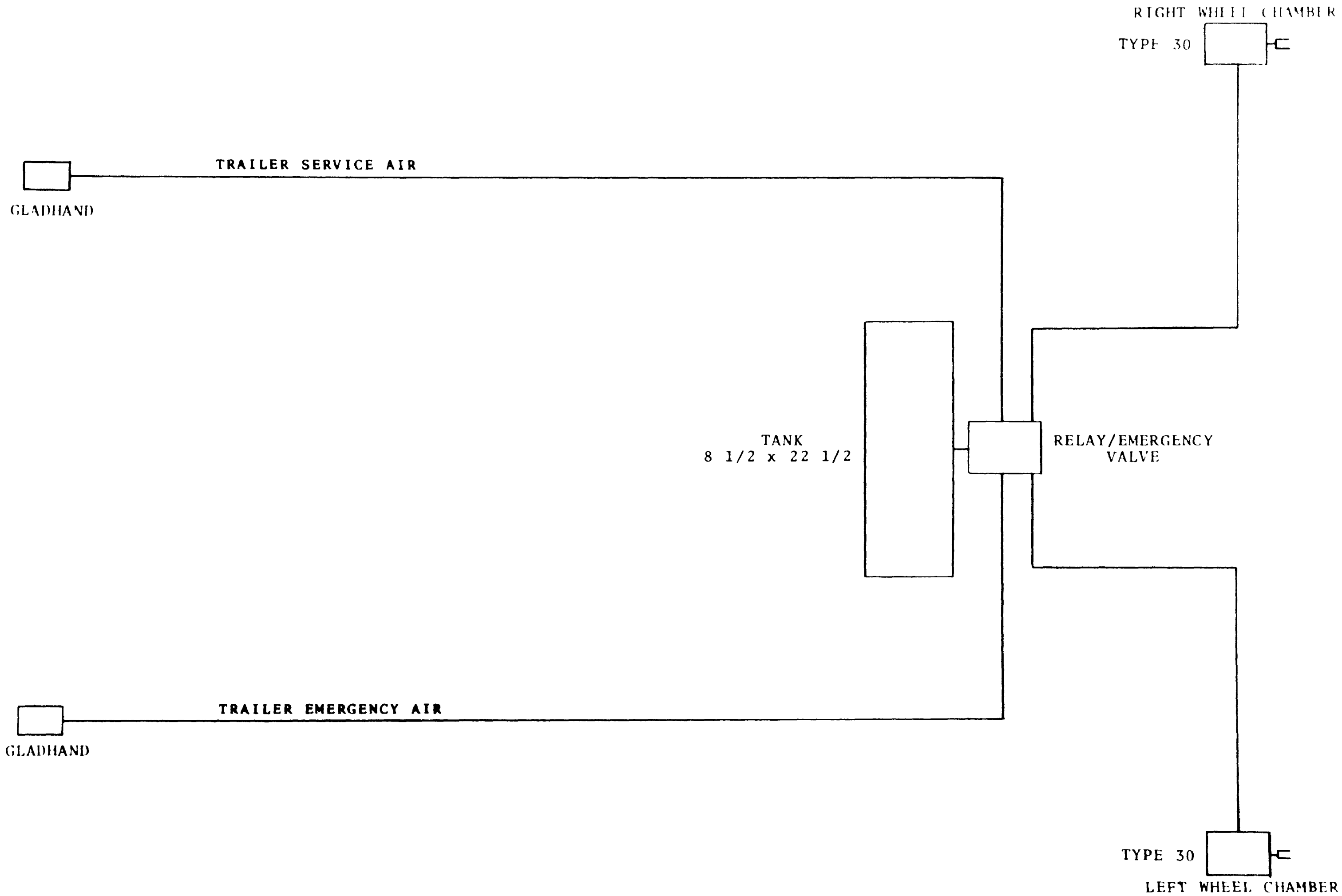


AXLE	1	2	3	TOTAL
COMBINATION EMPTY	5,420	7,460	6,050	18,930
COMBINATION LOADED	5,740	18,090	18,010	41,840

A.3.2 LOADING DIAGRAM: 2-S1 TRACTOR-TRAILER, FORD F-7000 TRACTOR, TRAILMOBILE 32-FT VAN TRAILER



A.3.3 BRAKE SYSTEM SCHEMATIC: FORD F-7000 TRACTOR (4x2)



A.3.4 BRAKE SYSTEM SCHEMATIC: TRAILMOBILE 32-FT VAN TRAILER

A.3.5 VEHICLE SPECIFICATIONS

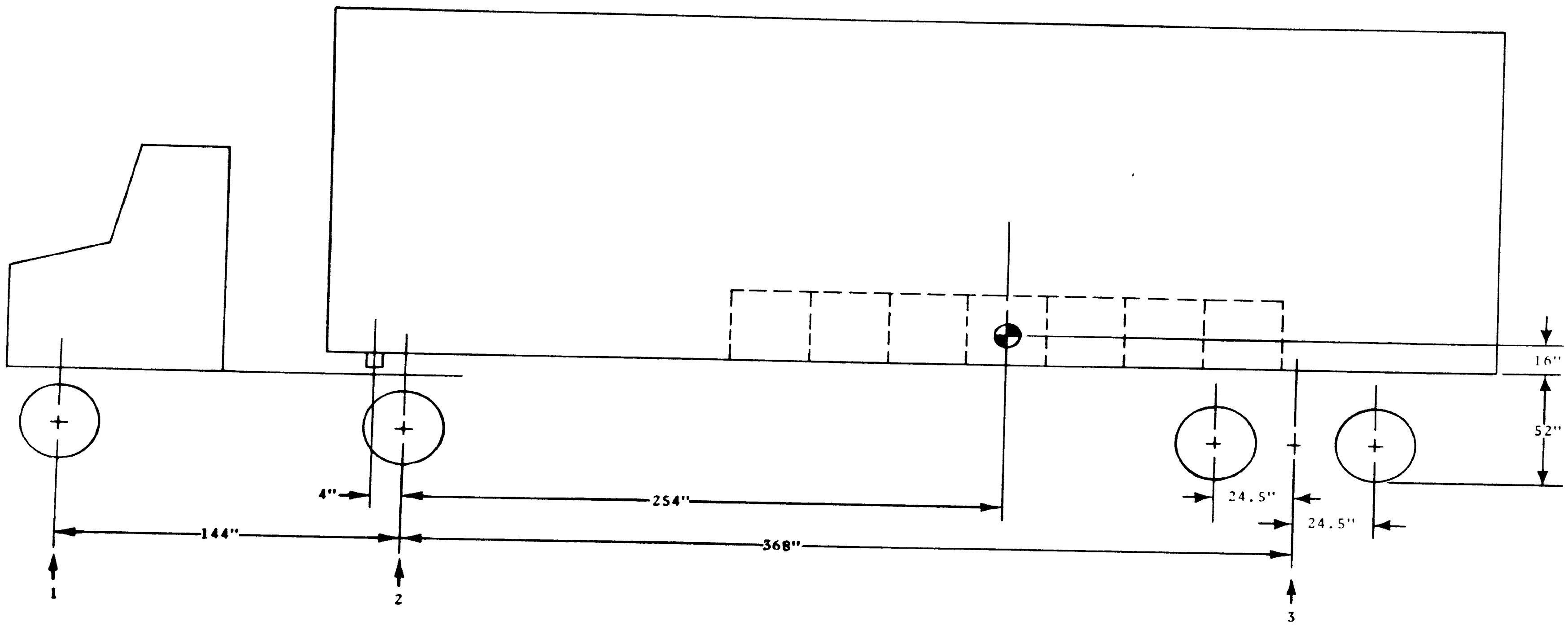
Tractor-Trailer 2-S2
Tractor Type: CBE, 2-axle
Make: Ford Model: F-7000 Year: 1970
Identification Number: K704 UG 31185
Engine: Caterpillar V-200
Trailer Type: Van, tandem axle
Make: Fruehauf Model: VB-6-F2-40 Year: 1967

Tires	Manufacturer	Size	Tire Pressure, psi
Tractor Front	Firestone	10 x 20	60
Tractor Rear	Goodyear	10 x 20 Duals	75
Trailer Rear	Goodyear	11 x 22.5 Duals	60
Trailer Tandem	Goodyear	11 x 22.5 Duals	60

Brakes	Manufacturer	Size	Type
Tractor Front	---	16 x 2.5	S-Cam
Tractor Rear	Eaton	16.5 x 6	S-Cam
Trailer	Rockwell	16.5 x 7	Wedge

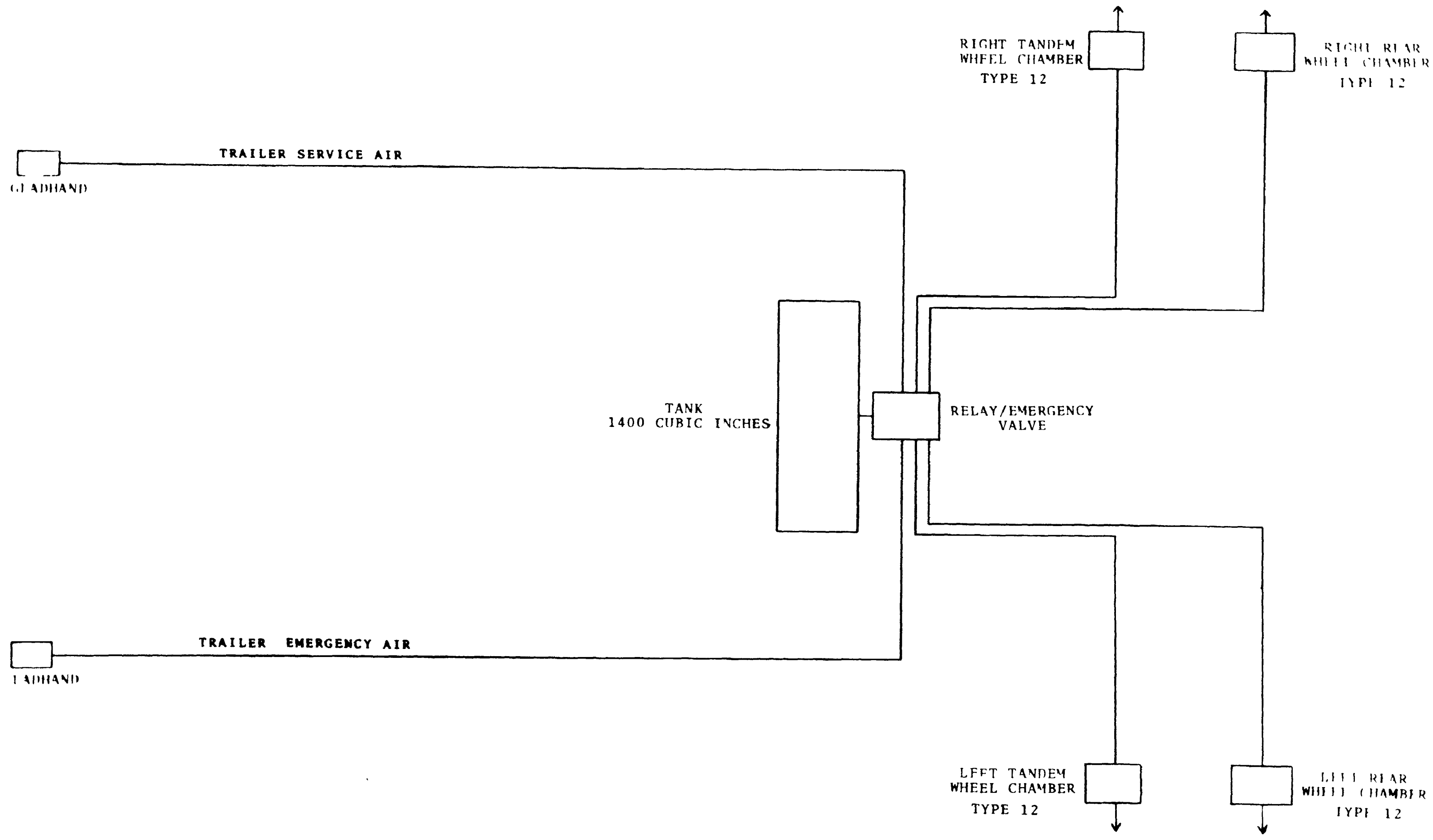
Brake Linings	Manufacturer	Type
Tractor Front	Bendix	H-3149A/H-3149
Tractor Rear	Molded Mat'ls	MMD-16
Trailer	Molded Mat'ls	MMD-16

Emergency System: Standard air



AXLE	1	2	3	TOTAL
COMBINATION EMPTY	5,420	7,590	7,840	20,850
COMBINATION LOADED	6,400	17,990	31,990	56,380

A.3.6 LOADING DIAGRAM: 2-S2 TRACTOR-TRAILER, FORD F-7000 TRACTOR, FRUEHAUF 40-FT VAN TRAILER



A.3.7 BRAKE SYSTEM SCHEMATIC: FRUEHAUF 40-FT VAN TRAILER

A.3.8 VEHICLE SPECIFICATIONS

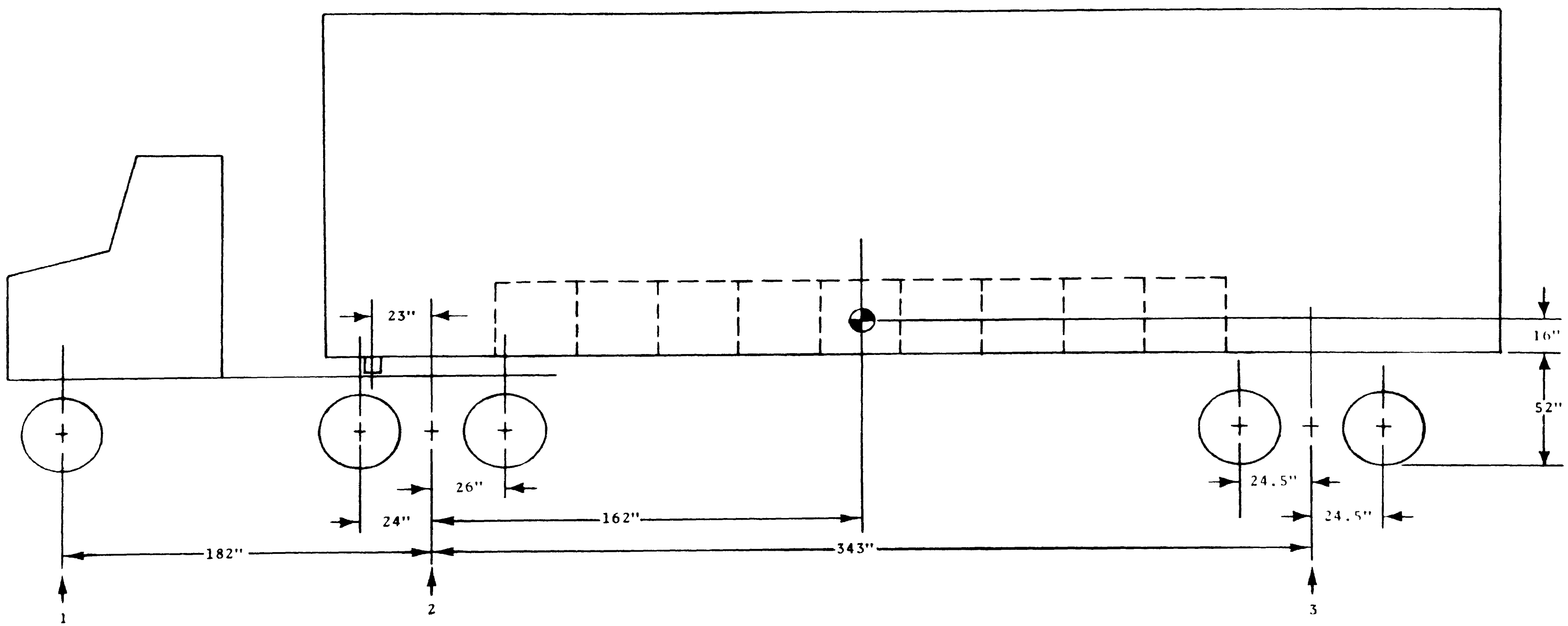
Tractor-Trailer 3-S2
Tractor Type: CBE, 3-axle
Make: Diamond Reo Model: C11464DF Year: 1970
Identification Number: DRE 65HC 581128
Engine: Detroit 8V-71N
Trailer Type: Van, tandem Axle
Make: Fruehauf Model: VB-6-F2-40 Year: 1967

Tires	Manufacturer	Size	Tire Pressure, psi
Tractor Front	Goodyear	11 x 24.5	95
Tractor Rear	Goodyear	11 x 24.5 Duals	55
Tractor Tandem	Goodyear	11 x 24.5 Duals	55
Trailer Rear	Goodyear	11 x 22.5 Duals	60
Trailer Tandem	Goodyear	11 x 22.5 Duals	60

Brakes	Manufacturer	Size	Type
Tractor Front	None	---	---
Tractor Rear	Rockwell	15 x 7	Wedge
Trailer	Rockwell	16.5 x 7	Wedge

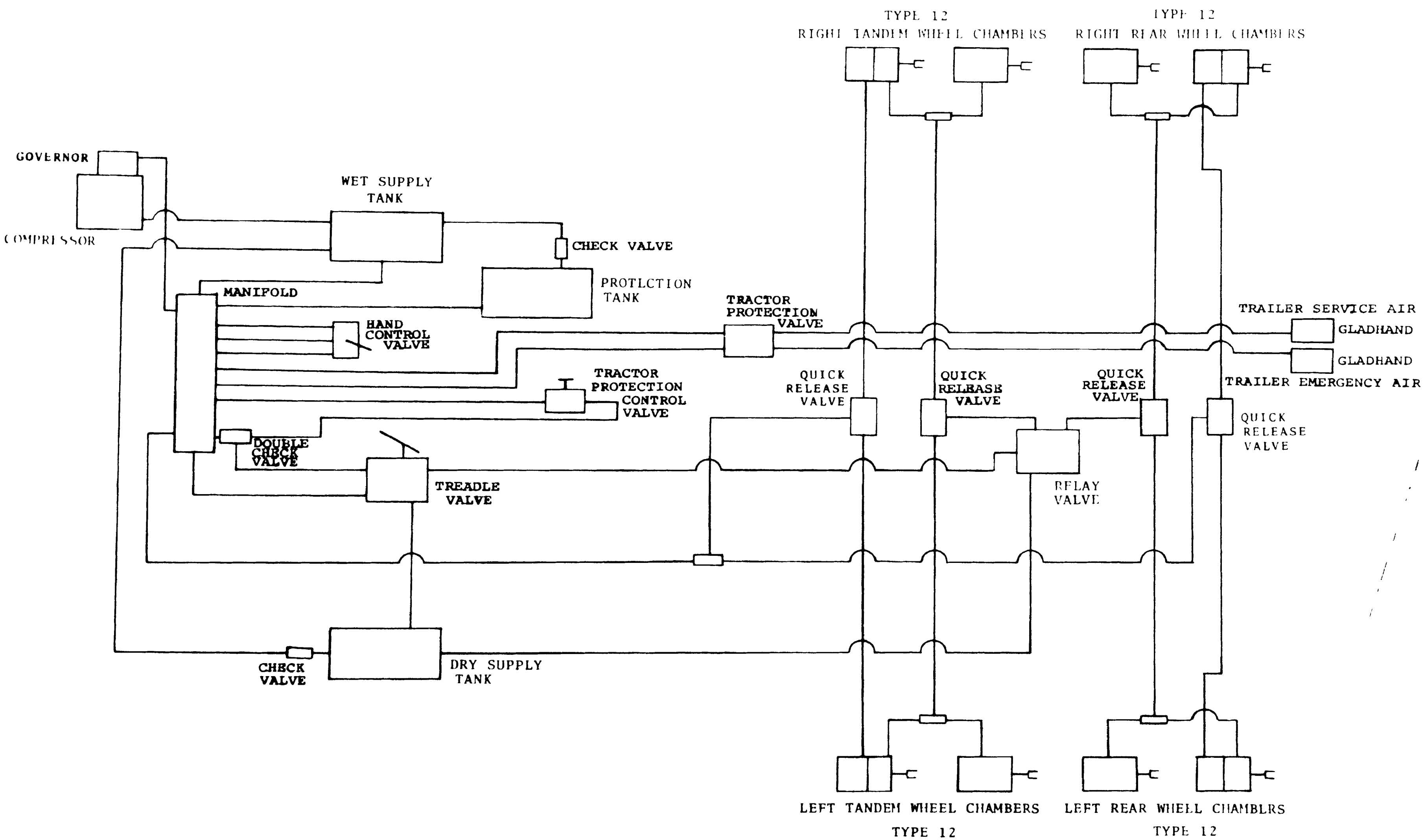
Brake Linings	Manufacturer	Type
Tractor Front	---	---
Tractor Rear	ABB	693-551D
Trailer	Molded Mat'ls	MMD-16

Emergency System: Standard air with spring brakes on tractor



AXLE	1	2	3	TOTAL
COMBINATION EMPTY	9,020	10,710	8,040	27,770
COMBINATION LOADED	11,420	32,240	31,990	75,650

A.3.9 LOADING DIAGRAM: TRACTOR-TRAILER 3-S2, DIAMOND REO C11464DF TRACTOR, FRUEHAUF 40-FT VAN TRAILER



A.3.10 BRAKE SYSTEM SCHEMATIC: DIAMOND REO C11464DF (6x4)

A.3.11 VEHICLE SPECIFICATIONS

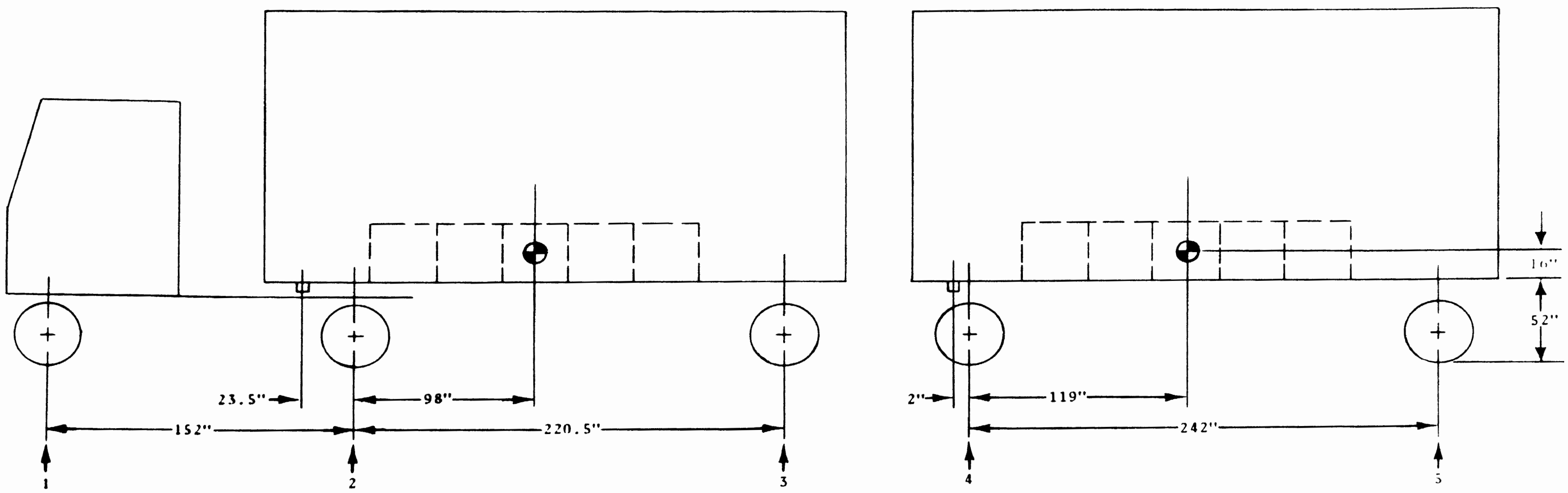
Doubles Combination 2-S1-2
Tractor Type: COE, 2-axle
Make: IHC Model: CO4070A Year: 1969
Identification Number: 2294716358744
Engine: Detroit
Trailers Type: Double Van
Make: Brown (Clark) Model: 226CXD3H1 Year: 1969

Tires	Manufacturer	Size	Tire Pressure, psi
Tractor Front	Firestone	11.00 x 22.5	95
Tractor Rear	Firestone	11.00 x 22.5 Duals	75
Trailers	Clark (General)	10.00 x 20 Duals	75

Brakes	Manufacturer	Size	Type
Tractor Front	Rockwell	15 x 3-1/2	Wedge
Tractor Rear	Rockwell	15 x 7	Wedge
Trailer	Schuler	16.5 x 7	S-Cam

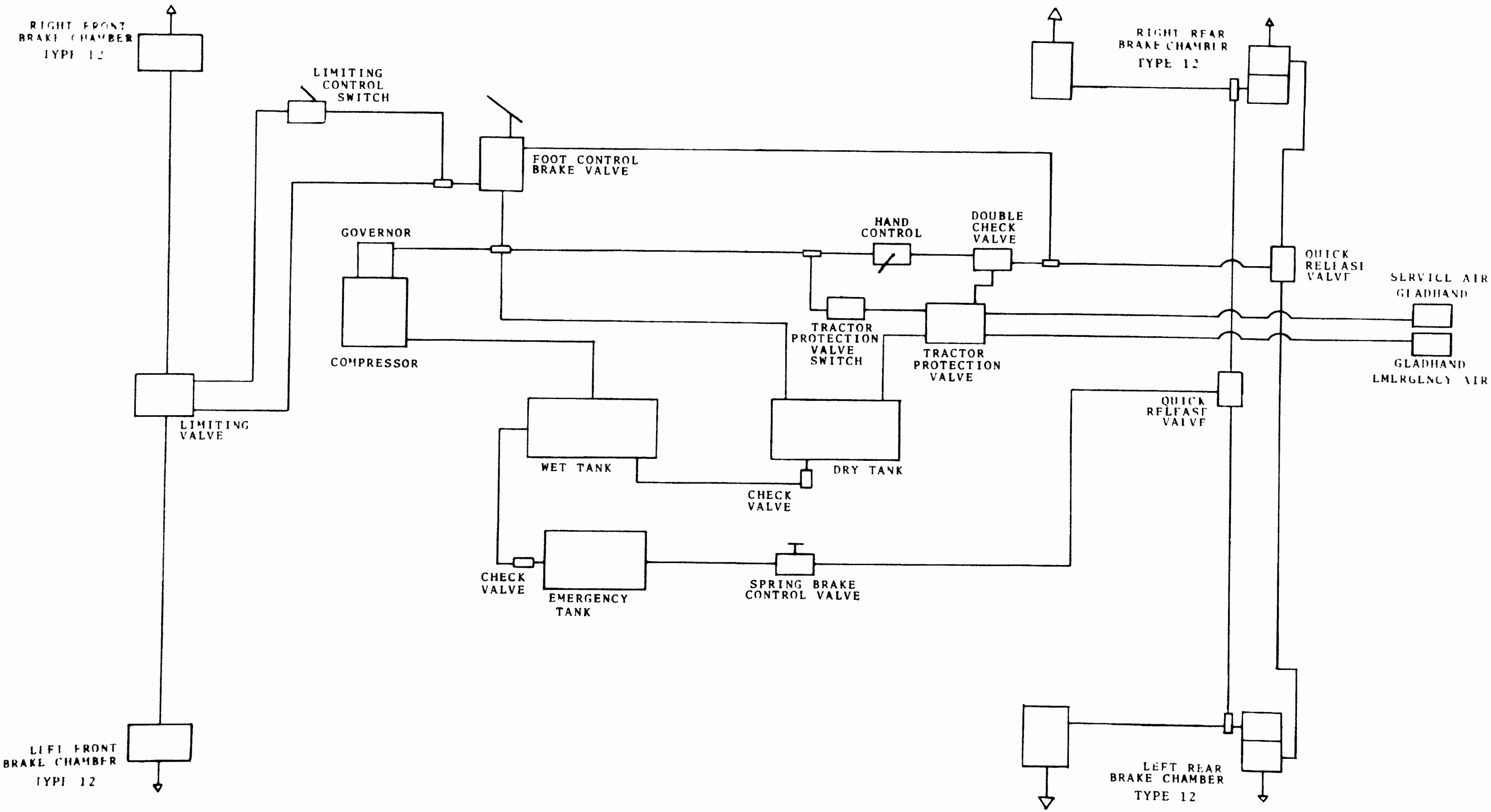
Brake Linings	Manufacturer	Type
Tractor Front	Molded Mat'ls	MMB-62
Tractor Rear	Molded Mat'ls	MMB-16
Trailer	ABB	693-551

Emergency System: Standard air with spring brakes on tractor

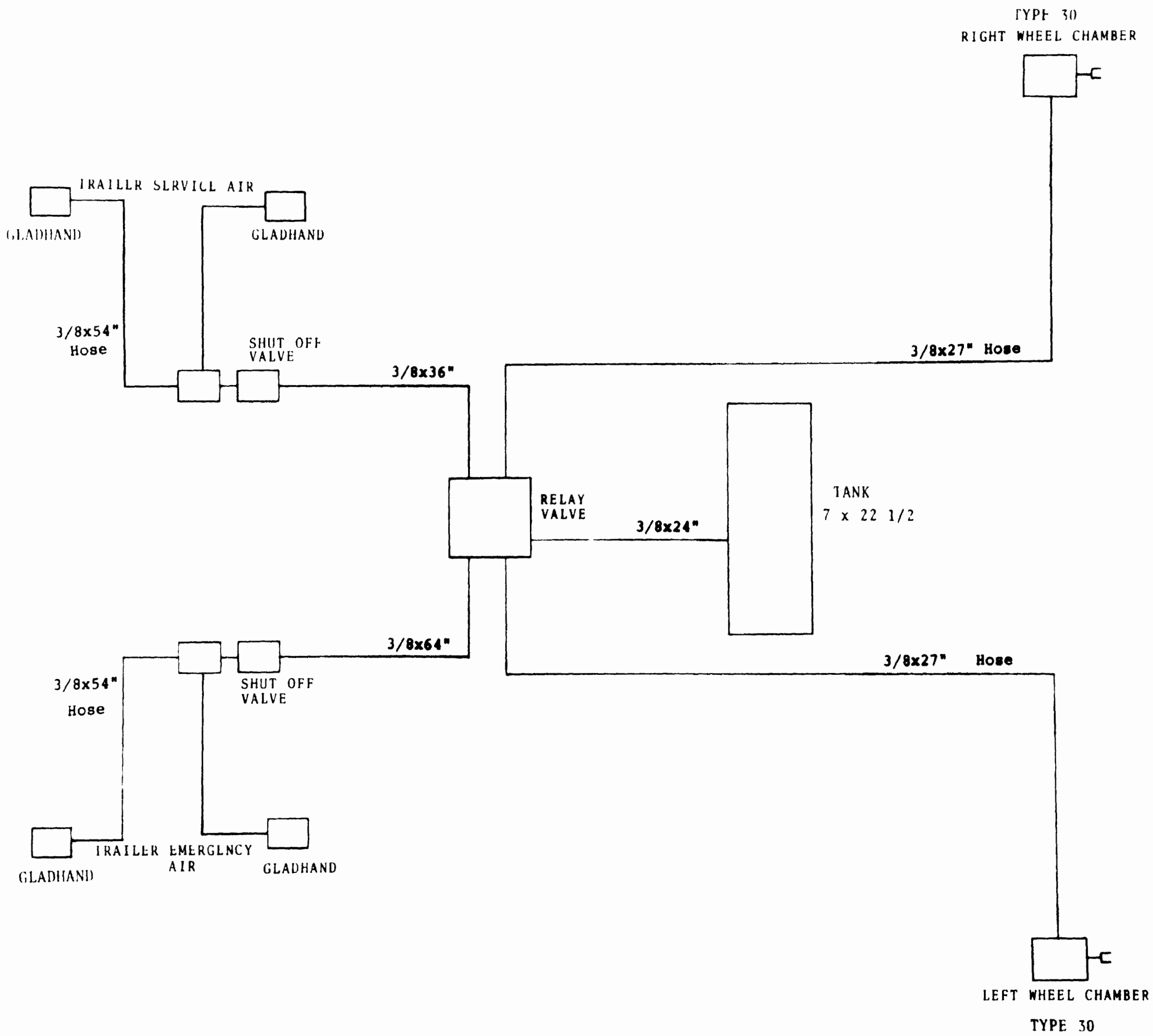


AXLE	1	2	3	4	5	TOTAL
COMBINATION EMPTY	8,710	6,510	4,950	4,250	4,450	28,870
COMBINATION LOADED	11,100	18,020	17,940	18,035	18,170	83,265

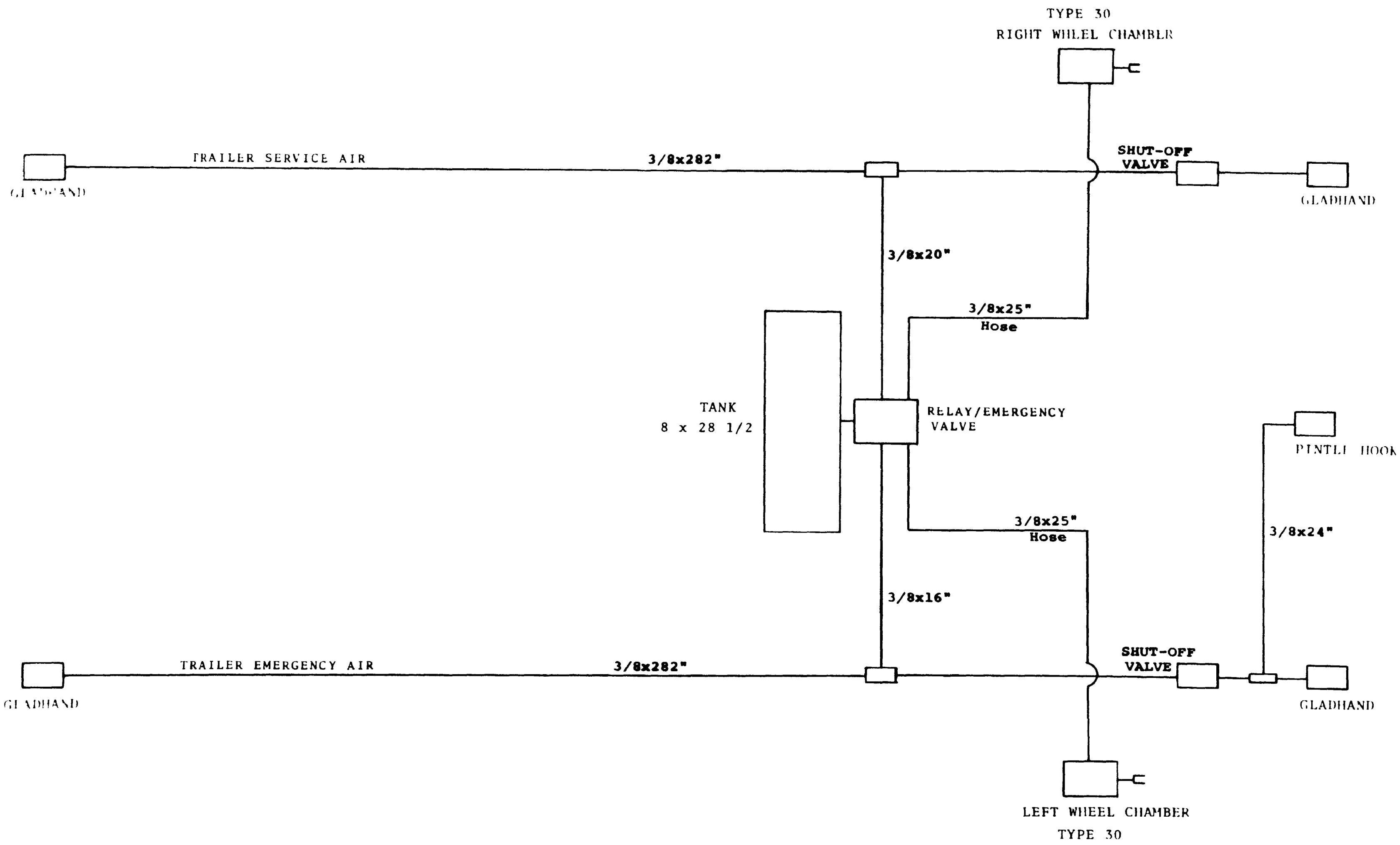
A.3.12 LOADING DIAGRAM: DOUBLES COMBINATION 2-S1-2, IHC CO4070A TRACTOR, CLARK 26-FT DOUBLE VAN TRAILERS



A.3.13 BRAKE SYSTEM SCHEMATIC: IHC CO4070A TRACTOR (4x2)



A.3.14 BRAKE SYSTEM SCHEMATIC: TRAILER DOLLY



A.3.15 BRAKE SYSTEM SCHEMATIC: SEMITRAILER—BROWN (CLARK)—27-FT

A.4 Vehicles Equipped with Advanced Systems

A.4.1 VEHICLE SPECIFICATIONS

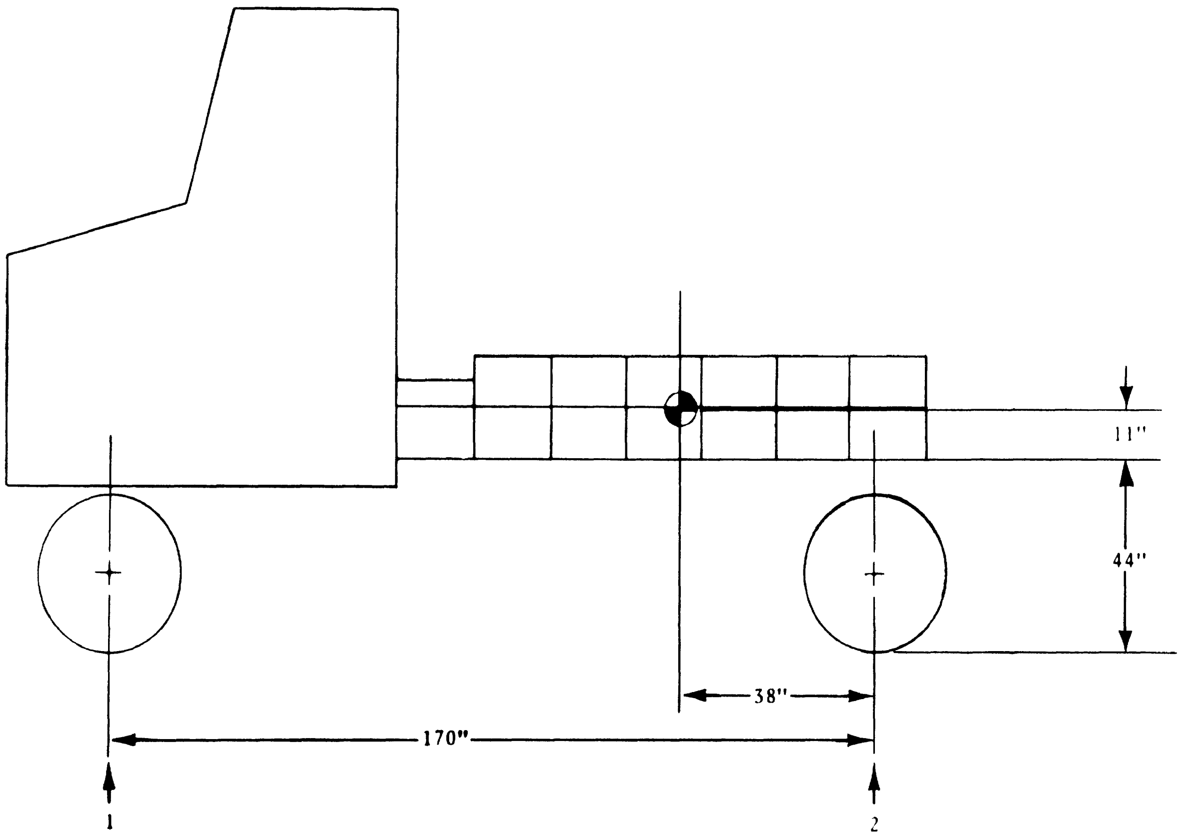
Vehicle Type: 2-axle flatbed
Make: Ford Model: F-1000 Year: 1966
Identification Number: 780593
Engine: Ford V-8 534CID
Transmission: 5-speed manual Rear Axle: 2-speed

Tires	Manufacturer	Size	Tire Pressure, psi
Front Axle	Firestone	10 x 20	75
Rear Axle	Firestone	10 x 20 Duals	75

Brakes	Manufacturer	Size	Type
Front Axle	Bendix	15.63 Dia.	Disk Series B-1
Rear Axle	Bendix	15.63 Dia.	Disk Series B-2

Brake System: Full power hydraulic, front/rear dual circuit

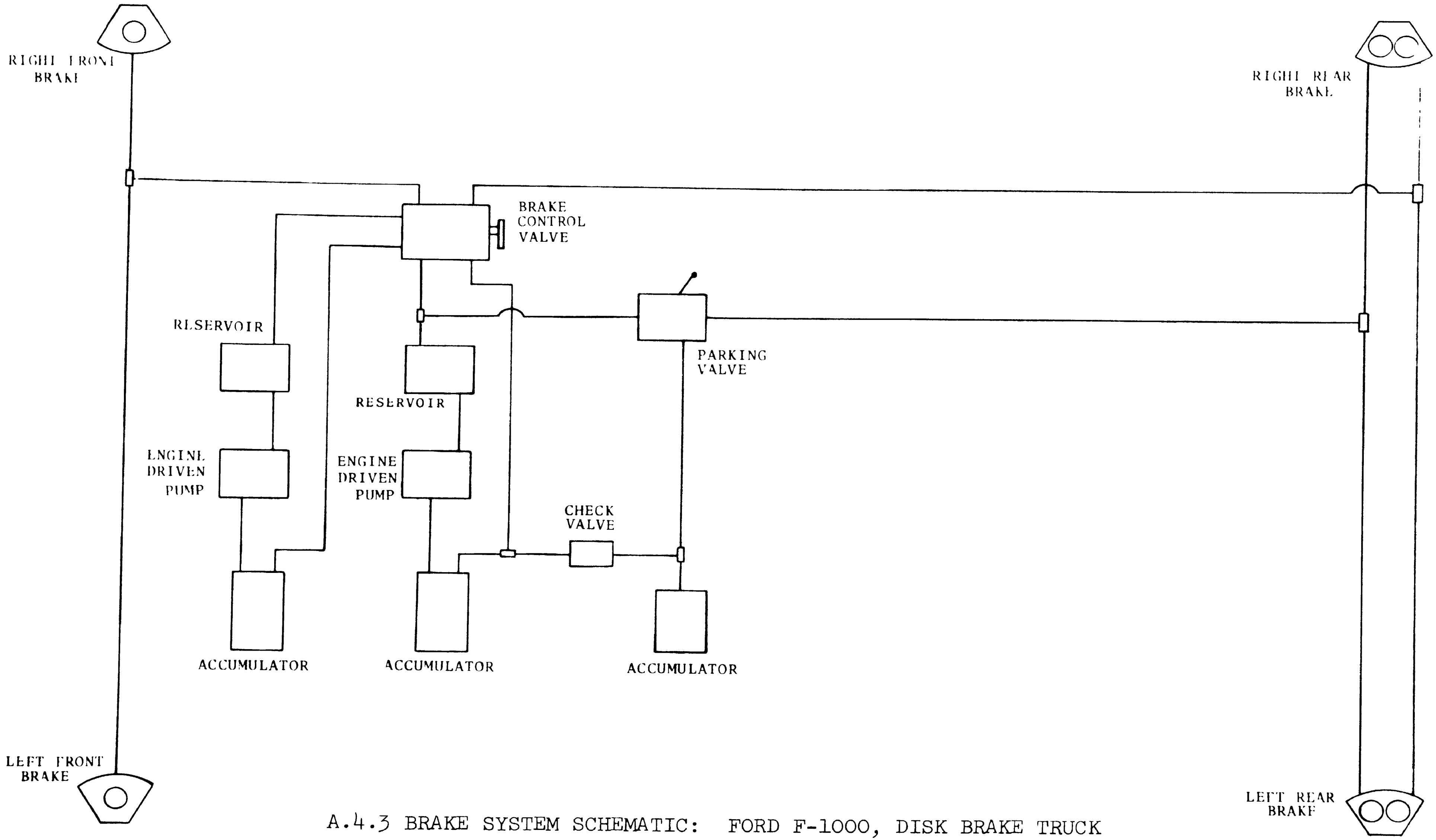
Emergency/Parking Brake: Spring brakes, rear axle



AXLE	1	2	TOTAL
EMPTY	6,480	7,100	13,580
LOADED	9,660	18,090	27,750

LOAD C.G.

A.4.2 LOADING DIAGRAM, DISK BRAKE TRUCK: FORD F-1000 FLATBED



A.4.3 BRAKE SYSTEM SCHEMATIC: FORD F-1000, DISK BRAKE TRUCK

A.4.4 VEHICLE SPECIFICATIONS

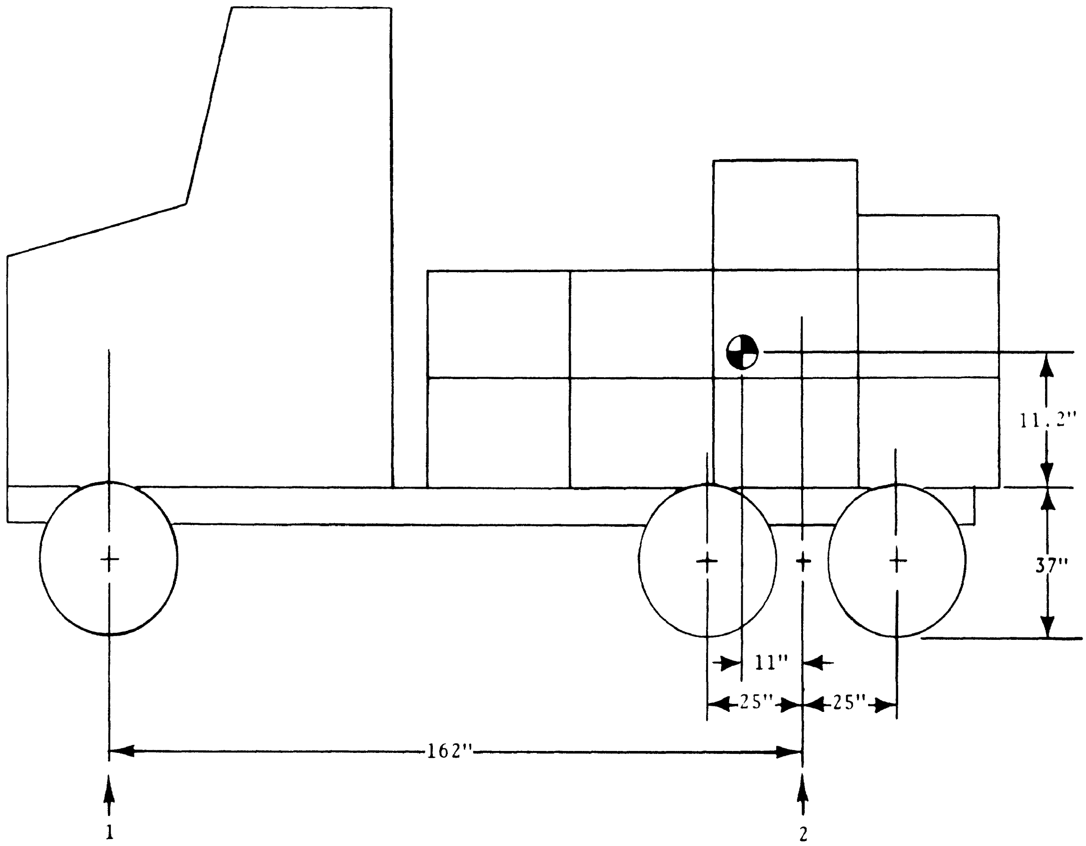
Tractor-Trailer 3-S2 (Vehicle 12)
Tractor Type: CBE, 3-axle
Make: White Model: 4564TD Year: 1967
Identification Number: 695855
Engine: Cummins NHC7-270
Trailer Type: Platform, tandem axle
Make: Fruehauf Model: PB-F240SP Year: 1969

Tires	Manufacturer	Size	Tire Pressure, psi
Tractor Front	Remington	10 x 20	85
Tractor Rear	Remington	10 x 20 Duals	70
Tractor Tandem	Remington	10 x 20 Duals	70
Trailer Rear	Remington	10 x 20 Duals	70
Trailer Tandem	Remington	10 x 20 Duals	70

Brakes	Manufacturer	Size	Type
Tractor Front	Rockwell	15 x 4	Double Wedge
Tractor Rear	Eaton	16.5 x 7	S-Cam
Trailer	Fruehauf	16.5 x 7	S-Cam

Brake Linings	Manufacturer	Type
Tractor Front	---	---
Tractor Rear	Raybestos	RM 3220/RM3219A
Trailer	Molded Mat'ls	MMD-39EE

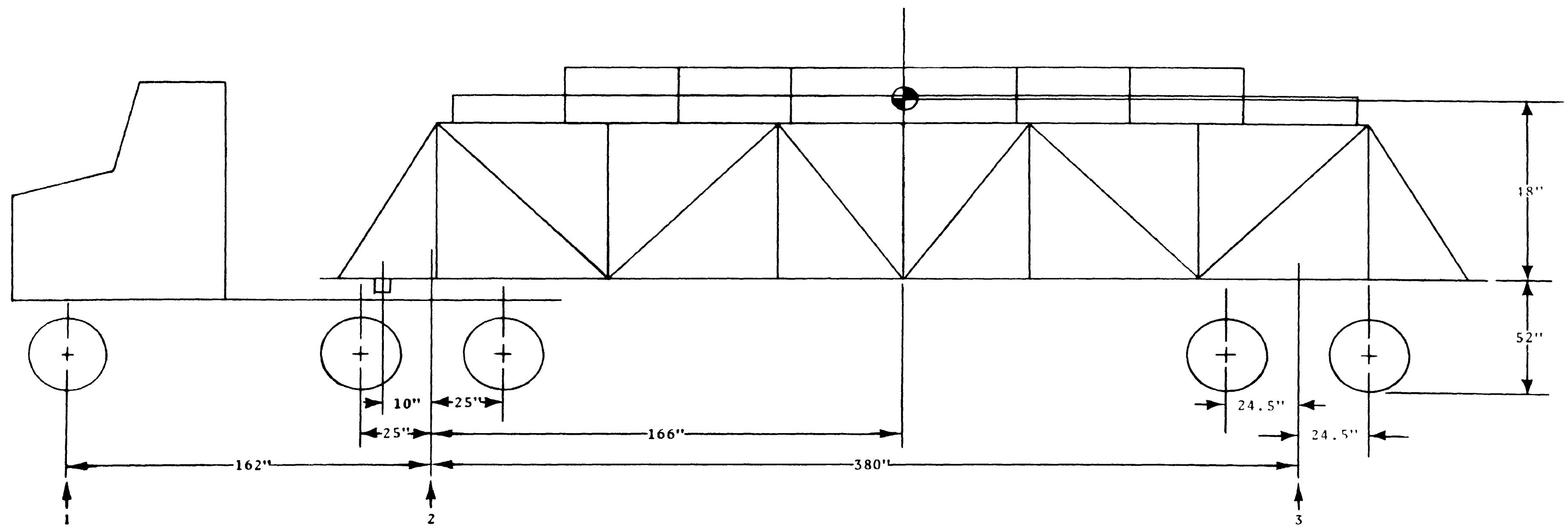
Emergency System: Standard with spring brakes on tractor



AXLE	1	2	TOTAL
EMPTY	8,620	8,280	16,900
LOADED	10,340	33,890	44,230

LOAD C.G.

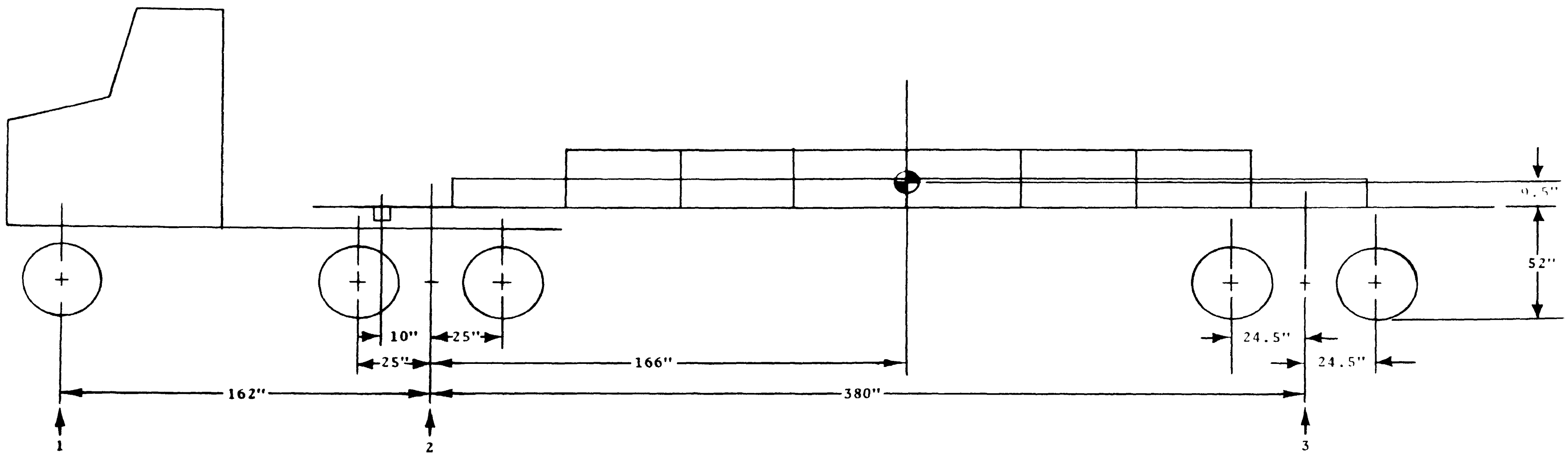
A.4.5 LOADING DIAGRAM: WHITE 4564TD TRACTOR



AXLE	1	2	3	TOTAL
COMBINATION EMPTY	8,910	12,415	8,035	29,360
COMBINATION LOADED	10,235	33,915	33,630	77,780

LOAD C.G.

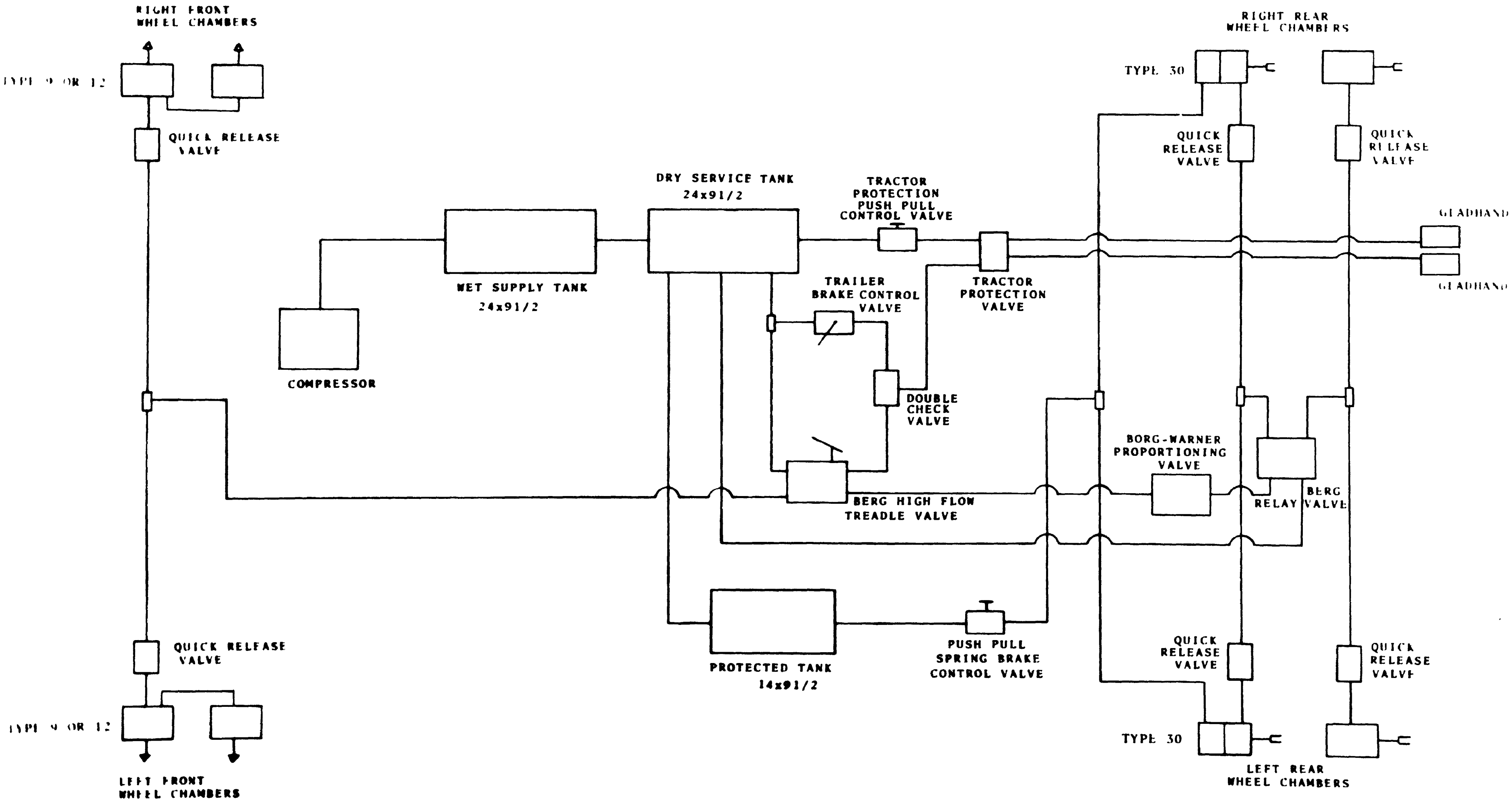
A.4.6 LOADING DIAGRAM: WHITE 4564TD TRACTOR, FRUEHAUF 40-FT FLATBED TRAILER, HIGH-C.G. LOAD



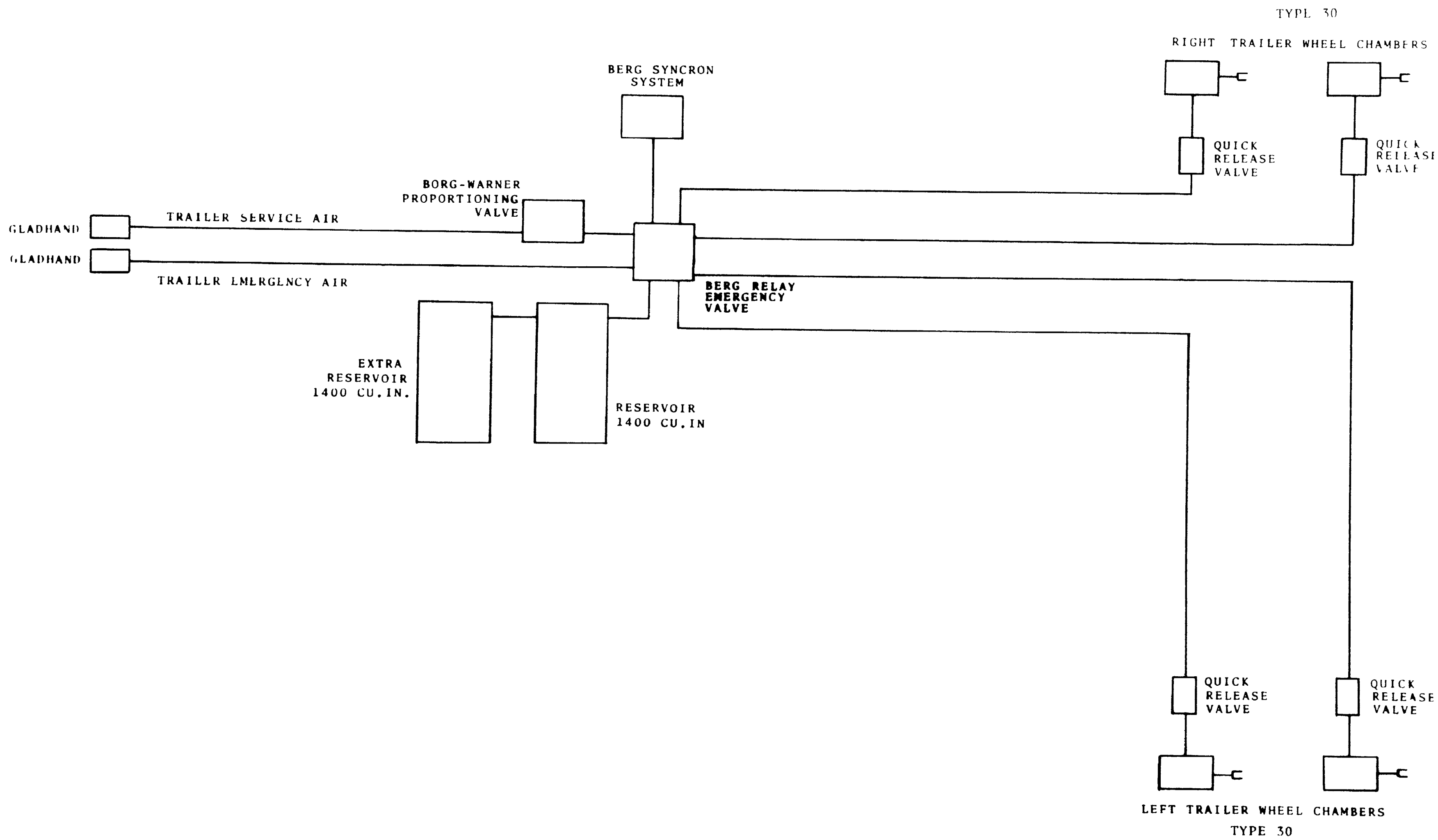
AXLE	1	2	3	TOTAL
COMBINATION EMPTY	8,910	12,415	8,035	29,360
COMBINATION LOADED	10,235	33,915	33,630	77,780

LOAD C.G.

A.4.7 LOADING DIAGRAM: WHITE 4564TD TRACTOR, FRUEHAUF 40-FT FLATBED TRAILER, LOW-C.G. LOAD



A.4.8 BRAKE SYSTEM SCHEMATIC: WHITE TRACTOR 4664TD (6x4)



A.4.9 BRAKE SYSTEM SCHEMATIC: FRUEHAUF TRAILER PBF 240SP

A.4.10 VEHICLE SPECIFICATIONS

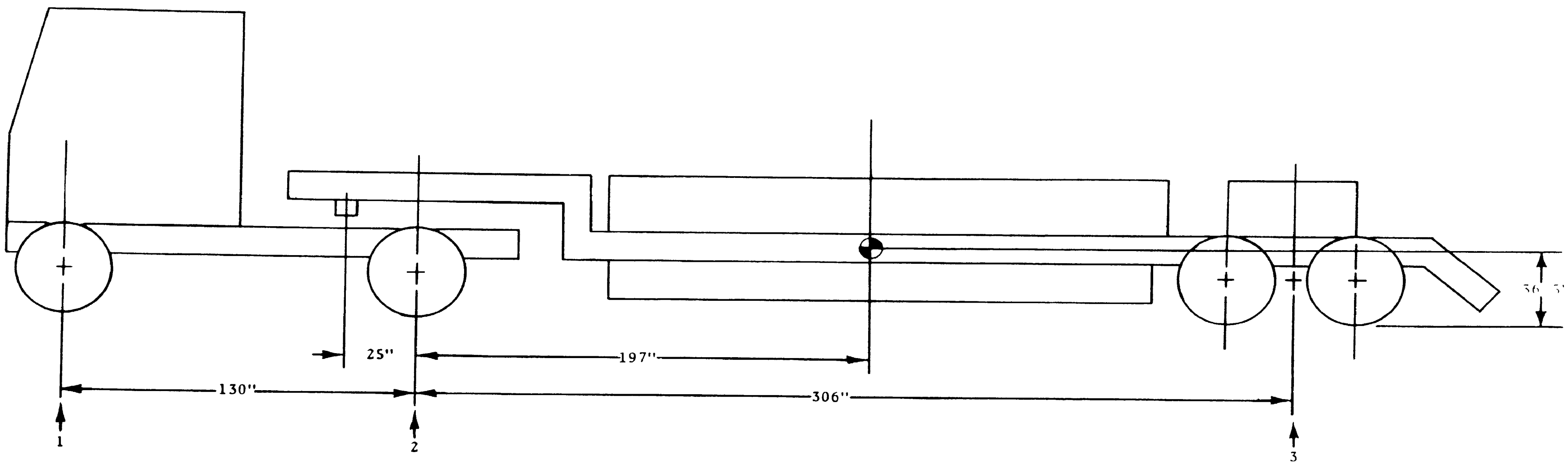
Tractor-Trailer 2-S2 (Vehicle 14)
Tractor Type: COE, 2-axle
Make: Brockway Model: N-4S77-4 Year: 1963
Identification Number: 61343
Engine: Cummins NH-250
Trailer Type: Lowboy
Make: Arrow Model: SCR-22-35 Year: 1967

Tires	Manufacturer	Size	Tire Pressure, psi
Tractor Front	Goodyear	10 x 22	85
Tractor Rear	Goodyear	10 x 20 Duals	85
Trailer Rear	Goodyear	10 x 20 Duals	85
Trailer Tandem	Goodyear	10 x 20 Duals	85

Brakes	Manufacturer	Size	Type
Tractor Front	Eaton	16.5 x 4.5	S-Cam
Tractor Rear	Eaton	16.5 x 7	S-Cam
Trailer	Eaton	16.5 x 7	S-Cam

Brake Linings	Manufacturer	Type
Tractor Front	ABB	551DPC
Tractor Rear	Carlisle	MMD16
Trailer	Carlisle	MMD16

Emergency System: Standard



AXLE	1	2	3	TOTAL
TRACTOR BOBTAIL	8,700	5,500	-	14,200
COMBINATION EMPTY	9,910	7,710	9,340	26,960
COMBINATION LOADED	12,100	17,700	31,700	61,500

C.G. LOAD + TRAILER

A.4.11 LOADING DIAGRAM: BROCKWAY COE N 4577-4 TRACTOR, ARROW SCR-22-35 LOWBOY

Appendix B

TEST PROCEDURES AND INSTRUMENTATION

B.1 TEST PROCEDURES

The following is a detailed description of the purpose, procedure, measurement, and data presentation for each of the tests performed on the vehicles included in this program. Essentially, the tests were conducted in the same way for each vehicle, with exceptions as noted. Where a vehicle could not reach the velocity required in these procedures, the test was conducted at the maximum speed attainable and the data corrected, if possible, for velocity error.

B.1.1 EFFECTIVENESS TEST

Purpose: Determine the braking capability of the test vehicle under normal operating conditions.

Procedure: With the vehicle traveling initially in a straight line on approximately level ground (maximum ±1% grade) at test speed, apply brake-pedal force necessary to maintain the specified brakeline pressure until the vehicle stops completely. This test will be conducted with the hottest brakes at 200°F before the application of the brake. Conduct the test at no less than five constant line pressure levels, i.e., 25, 50, 75, 90, and 100 percent of the line pressure required to lock the wheels. In the event that wheels do not lock up, line pressure levels will be based on 25, 50, 75, 90, and 100 percent of the line pressure required to maintain maximum achievable vehicle deceleration. Test speed for the articulated and integral vehicles and inter-city bus shall be 60 mph and for the city bus and school bus, 40 mph. In locked wheel stops, pedal force will be maintained throughout the complete stop only if the vehicle remains directionally stable.

Measurement: Speed, longitudinal deceleration, brake-line pressure at each axle and at the brake control valve, individual brake-lining temperatures (both before and after the test), individual wheel rotation (to indicate wheel lockup), and stopping distance by means of fifth wheel distance counter for all stops and actual measurement with detonator in minimum distance stops.

Data Presentation: Compute pedal force for test brake-line pressures. Plot pedal force versus deceleration for each vehicle load condition. Indicate deceleration level at which wheel(s) lockup and state which wheels lockup. Tabulate stopping distances at all line pressures for all vehicles.

B.1.2 BRAKE FAILURE TEST

Purpose: Determine the braking capabilities of the test vehicle under possible failure modes.

Procedure: The procedure will be exactly as specified for the effectiveness tests, except that tests will be repeated in the loaded and unloaded conditions for the system failures applicable to the particular test vehicle.

(1) Small truck, Chevrolet C30: power boost failure, front hydraulic line failure, rear hydraulic line failure.

(2) Medium truck, I.H. Loadstar 1700: power boost failure.

(3) Large truck, Chevrolet J70: air brake system has no failure protection modes. One stop will be made with parking brake.

(4) School bus, Ford F-750: emergency system consists of separate air supply to brakes controlled from hand lever. Brakes can be modulated. This system will be used for emergency braking test.

(5) Intercity bus, MC-7: emergency system consists of separate air supply to brakes. Control is not modulated. This system will be used for one emergency stop.

(6) Tractor-trailer combination: from an initial speed of 20 mph, trailer brakes only are set in emergency application by actuating the tractor protection valve. If the tractor is equipped with spring brakes, one stop will be made from 20 mph actuating these brakes only.

(7) GMC coach: make one stop from 40 mph with the hand operated mechanical parking brake. Also one stop will be made by opening the rear door, which automatically actuates the rear brakes.

(8) Disc brake truck: front hydraulic line failure, rear hydraulic line failure.

Measurements: Same as for effectiveness tests.

Data Presentation: Plot average pedal force as a function of deceleration for the loaded and unloaded conditions under each type of system failure. Note occurrences of wheel lockup. Tabulate minimum stopping distances for all vehicles in the loaded and unloaded condition under each type of system failure.

B.1.3 FADE AND RECOVERY TEST

Purpose: Determine the braking capability of test vehicle under conditions which produce fade.

Procedure: The test is performed with the vehicle fully loaded. Before performing the test, warm up the brakes until the hottest brake lining temperature is 200°F. One baseline snub will be made from 40 mph to 20 mph at a deceleration of 10 fpsps. The fade test will follow immediately after the baseline snub. Apply successive snubs at a deceleration of 15 ft/sec^2 (or maximum deceleration achieved during Post-Burnish Effectiveness Test) reducing speed from 60 mph (city bus and school bus, 40 mph) to 10 mph until the braking system fails to maintain the deceleration of 15 ft/sec^2 (or deceleration used for this test) for the full brake snub. Upon reaching 10 mph speed at the end of each snub, the vehicle is to be accelerated at the maximum engine capability to the specified test speed (60 mph for tractor-trailer combinations and 40 mph for city bus and school bus). Vehicle must remain directionally stable in the 12-ft lane during each brake snub. Snubs are to be made in high gear with manual transmissions and in drive position with automatic transmissions. Due to limited acceleration capability of the tractors used with semitrailers, the time to accelerate from 10 mph to 60 mph may be such to allow the brakes to cool, making it impossible to fade the brakes. The test will be aborted if the brakes do not fade even after 10 snubs. If the fade test is successful, a recovery test as specified in SAE Recommended Practice J786 will be conducted. This test involves application of 10 snubs at a deceleration of 10 ft/sec^2 at intervals of 2.0 miles maintaining, if possible, a speed interval of 40-20 mph at each snub.

Measurement: Speed, longitudinal deceleration, brakeline pressure at each axle, and brake lining temperature at each wheel, elapsed time for fade test, elapsed time for recovery test.

Data Presentation: Calculate pedal force for the average line pressure during each snub. Plot pedal force and hottest brake temperatures verses snub number for both fade and recovery tests for each vehicle. Tabulate number of snubs achieved during fade test, and highest lining temperature during fade, for all the vehicles tested.

B.1.4 BRAKE RATING TEST

Purpose: Determine the horsepower absorption capabilities of the braking system of the vehicle tested.

Procedure: Calculate the braking force required to maintain the fully loaded test vehicle at a constant downgrade speed on a 7 percent grade. Tow the fully loaded test vehicle on a level surface at test speed with brakes off, engine running at idle speed and transmission in neutral.* Using the instrumented tow bar, measure the resulting force which is the sum of aerodynamic

*Test speed for the light truck was 40 mph, and for all other vehicles tested ranged from 22 to 30 mph depending upon weight of the test vehicle and power available in the towing vehicle.

drag forces and rolling resistance. Add the calculated brake force to this sum to obtain the total test towing force. Again towing the test vehicle on a level surface at test speed, engine at idle speed and transmission in neutral, gradually apply the brakes on the towed vehicle until the total test towing force is obtained. Note the brake-line pressure on test vehicle. With the tow vehicle maintaining test velocity, and the towed vehicle maintaining the same brake-line pressure, continue the test until the towing force decreases by 15 percent, or the temperature in any of the brakes exceeds the maximum achieved in the fade test. For articulated vehicles the following procedure will be used.

(a) Calculate the test towing force for the combined vehicle by adding the rolling resistance and the braking forces.

(b) Calculate the test towing force for each vehicle, i.e., tractor and each trailer separately. The test towing force for each vehicle is in the same proportion to the test towing force for combination as the weight on the axles of the vehicle is to the total weight of the combination.

(c) Tow the loaded vehicle on a level track at a test speed with engine of towed truck at idle speed and transmission in neutral. Apply the trailer brake of the towed vehicle to produce the test towing force for the trailer as calculated in (b) above. Maintain this brake-line pressure and a tow velocity until the towing force decreases by 15 percent or the temperature on any of the brake linings exceeds the maximum achieved in the fade test.

(d) Repeat the test as per procedure in (c) above by applying the tractor brakes of the towed vehicle to produce the test towing force for the tractor as calculated in (b) above. If the tractor brakes cannot be applied alone without applying brakes on trailer, then the trailer will be disconnected.

Measurements: Forward velocity, brake line pressure, towing force, and brake lining temperatures.

Data Presentation: Plot brake force versus time for each vehicle tested. For all vehicles, tabulate horsepower absorbed by the brakes and resulting maximum brake temperatures. If possible, correlate the test results with those of the fade test for each vehicle.

B.1.5 BRAKE BALANCE TEST

Purpose: To determine if brakes are balanced to axle loads, for overall safety of the vehicle and for achieving optimum effectiveness of the brakes.

Procedure: Follow the procedure given in Section C(3) of SAE Recommended Practice J992a. Stops will be made using an intermediate brake-line pressure, 42 psi. Make a warmup stop from 40 mph. Next make three stops each from 20 mph at the same operating pressure at 1/2-mile intervals recording deceleration obtained by (a) tractor and trailer (all brakes), (b) tractor brakes only, and (c) trailer brakes only. The brakes are then checked for balance by insuring that the ratio of the partial brake-system deceleration to the full brake-system deceleration is equal to the ratio of the weight of each tractor or trailer (on its axle or axles) to the total weight of the combination, within a reasonable tolerance.

Measurement: Speed, longitudinal deceleration, brake-line pressures.

Data Presentation: Tabulate and compare the ratio of weights to the ratio of decelerations for all thr tractor-trailer combinations.

B.1.6 MINIMUM STOPPING DISTANCE TEST

Purpose: Determine the minimum stopping distance that can be attained by the test vehicle under the specified loading and road surface conditions and braking system configuration with no wheel lockup.

Procedure: With the vehicle traveling initially in a straight line at test speed on the specified road surface with cold brakes, i.e., hottest brake temperature at 200°F, ±10°F, apply maximum brake pedal force as rapidly as possible to stop the vehicle in the shortest distance without locking any wheels. Make at least three stops for each test condition. However, as many as 5 stops may be required.

Measurements: Deceleration, forward velocity, stopping distance, brake-line pressures, and individual wheel rotation (to indicate lockup). Individual brake temperatures will be noted before and after test.

Data Presentation: For each stop, tabulate maximum and average decelerations, stopping distance, and indicate occurrence of wheel lockup, identifying which wheels locked.

B.1.7 STATIC RESPONSE TIME TEST—AIR BRAKE VEHICLES

Purpose: Determine the brake application and release response characteristics for each set of brakes on the vehicle.

Procedure: With the vehicle at rest on a flat level surface, the brake pedal is depressed as rapidly as possible, hild for three seconds, and then released as rapidly as possible. Test is performed three times.

Measurement: Stop light switch actuation, pedal force, air pressures at output of treadle valve, at front axle, rear tractor axle, and at trailer axle.

Data Presentation: On the same chart, plot curves of air pressure versus time at treadly valve output and at each axle. Time is measured from stop light switch actuation.

B.1.8 PEDAL FORCE—LINE PRESSURE CALIBRATION

Purpose: Determine the relationship between the force applied to the brake pedal and the resulting air pressure output of the treadle valve.

Procedure: With the vehicle at rest on a flat, level surface, brake pedal force is gradually increased until maximum line pressure is achieved. The brake pedal is then released. For those vehicles with power boost systems the engine shall be running and for air brake vehicles the reservoir shall be at maximum operating pressure. Test is performed three times.

Measurement: Pedal force, and line pressure at output of treadle valve.

Data Presentation: Plot pedal force versus line pressure.

B.1.9 PARKING BRAKE TEST

Purpose: To determine effectiveness of spring parking brakes.

Procedure: With the test vehicle loaded and resting on a flat, level surface, attach the instrumented tow bar between the tow vehicle and the test vehicle. Set the parking brakes on one axle of the test vehicle. Slowly apply a load through the tow bar by means of the towing vehicle until the test vehicle starts to move. Repeat the test three times for each axle equipped with a parking brake.

Measurement: Tow bar force, velocity from fifth wheel, individual wheel rotation.

Data Presentation: Using the average tow bar force from the three tests, calculate the maximum grade at which the spring parking brakes would hold the vehicle. Tabulate average tow bar force and maximum grade for each vehicle, indicating which, if any, wheels slide during tests.

B.1.10 FINAL INSPECTION. As soon as all of the tests are completed, make a final inspection and measurement of linings, drums, and tires. Record results of this inspection.

B.2 INSTRUMENTATION

Instrumentation of the vehicles is specified for each test in Table 5. Brake lining temperatures will be monitored manually through a pyrometer head for effectiveness and emergency tests but will be recorded continuously on the oscillograph for fade, recovery, and brake rating tests. In the effectiveness and emergency tests, brake-line pressure will be displayed to the driver for making constant line pressure stops. In the fade and recovery tests, deceleration will be displayed to the driver on a U-tube decelerometer so that the required deceleration levels are strictly maintained. In the brake rating test, brakeline pressure will be displayed to the driver of the towed vehicle so that constant line pressure corresponding to the desired towing force may be maintained. Meanwhile, the observer shall monitor the oscillograph traces of towing force and brake lining temperatures for terminating the test when required criteria have been met.

Specifications for the instrumentation are as follows. Instrumentation and oscillographs were provided for and installed in each test vehicle by BADC, with the exception of Vehicle 14, which was supplied by Eaton, Yale, and Towne with instruments and oscillograph already installed. All of the instruments will be calibrated before use in testing.

B.2.1 INSTRUMENTATION FOR BASE-LINE VEHICLES, DISK BRAKE TRUCK, AND VEHICLE 12

Accelerometer: CEC Model 4-202, ±2.5 g, strain-gaged type, accuracy 3/4% of full scale or Statham A-3-1-350, ±1 g, strain-gaged type.

Fifth Wheel: Performance Measurements Model 1625, 120 mph maximum, accuracy 1/2% of full scale.

Pedal-Force Transducer: Bendix, strain-gaged type, 0-450 lb range, accuracy 1/2% of full scale.

Pressure Transducer: CEC Model 4-313-0001 g, 0-250 psi, and 4-313-0001 g, 0-2500 psi strain-gaged type, accuracy 1/2% of full scale.

Thermocouples: Bendix, chromel-alumel, 1600°F maximum ±1°F accuracy, Lewis Manufacturing Co. Pyrometer readout.

Pyrometer: Lewis Engineering 23B4, 0-1200°F, each division 25°F.

Wheel Lockup Indicators: Bicycle generators to produce current for go, no-go readout on oscillograph (accuracy specification not applicable). Vehicles 12 and 14 used output from wheel speed sensors used in antilock systems.

Oscillograph: CEC Model 5-124A light beam, 18 channel. For temperature recording, CEC Model 7-340 galvanometers with 6 hertz frequency response. For recording of dynamic variables, i.e., speed, deceleration, brake-line pressures, CEC Model 7-341 and Model 7-348 galvanometers with 60 hertz frequency response.

Line Pressure Gage: Marsh, 0-160 psi, accuracy ±1%.

Instrumented Tow Bar: Lebow Model 3116-103, strain-gaged type, ±20,000 lb with 50% overload capacity. Linearity 0.15% rated capacity. Tow bar designed and fabricated by HSRI (Fig. B-1). The load cell is calibrated by the manufacturer and a calibration resistor is supplied with the cell.

U-Tube Decelerometer: AAMCO Model #7350.

B.2.2 INSTRUMENTATION FOR VEHICLE 14. Since Eaton, Yale, and Towne furnished a complete vehicle ready for testing, separate instrumentation was used. The following is a list of the instrumentation used on this vehicle.

Data Recorder: Brush instruments, Mark 260, pressurized ink writing, 6 analog channels, 4 event channels.

Frequency Response:
50 Div.: Flat within ±2% full-scale to 40 Hz
10 Div.: Flat within ±2% full-scale to 100 Hz, 3 db down at 125 Hz

Signal Conditioner and Amplifier: (for pressure transducers) Manufactured by Eaton, Yale, and Towne, Inc., Research Center.

Amplifier Gain: 10 - 1 K variable
Frequency Response: 10 KHz (filter off)
Filter: Low pass, active filter, maximally flat, 3 db down at corner frequency, 40 db/decade roll-off

Pressure Transducers: Manufactured by Eaton, Yale, and Towne, Inc., Research Center. 350-ohm strain gages.

Nominal Output: 2.0 MV/volt - full scale
Accuracy: ±0.1% full scale
Natural Frequency: 14 kHz (approx. for 100 psi unit at full scale)

Accelerometer: Genisco Model GLH 402, potentiometric type, 1 K ohm resistance, ±2 g, magnetically damped.

Linearity: 1.25% of full scale
Resolution: 1%
Natural Frequency: 10 Hz

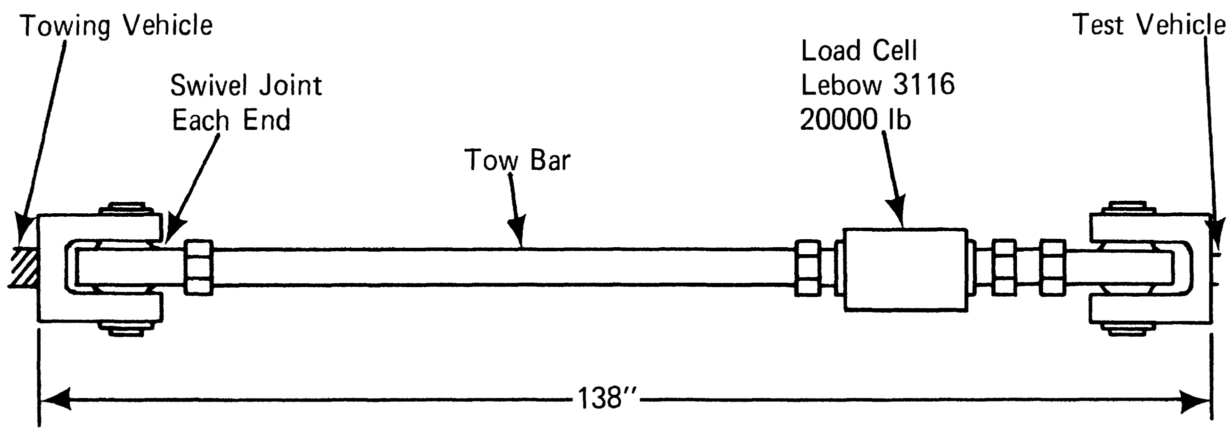


FIGURE B-1. INSTRUMENTED TOW BAR

Damping: .50 at 75°F
Output Filter: RC type filter
Short position: .1 sec time constant
Long position: .2 sec time constant

Fifth Wheel: Track Test made by LABECO. 26 in. x 2.125 pneumatic tire.

Velocity Transducer: Weston tachometer generator, type J-2, Model 750, Output; 6 V/100 rpm. Resistance: 20 ohms
Velocity Readout: Weston meter, dual range, Model 1971, 0-60, 0-120 mph.
Stopping Distance Indicator: Standard Electric Time Company, Special SelsynDrive Parisometer. Accuracy to be determined by comparing with road marking device.

Wheel Speed Indicator: Frequency to voltage converter. Manufactured by Eaton, Yale, and Towne, Inc., Research Center.

Input: Frequency proportional to wheel speed, 0-1 kHz
Output: 1.02 v/12 mph, full scale - 10 v (117 mph)
Response: from 10% to 90% of full scale, 50 milliseconds
Linearity: .3% full scale

Wheel Lock Indicator: Manufactured by Eaton, Yale, and Towne, Inc., Research Center.

Input: Signal from wheel speed conditioner
Output: Closure of contacts to operate event markers. Will indicate lockup at wheel speeds of 1 mph or lower. Actuation time of relay is 15 msec.

Brake Temperature Instrumentation: Iron-Constantan thermocouples, 16 gauge (I.C. -P-16)(mounted in brake shoes in accordance with SAE Brake System Road Test Code SAE J8436 and SAE J786). Thermocouples and extension wires matched to the following pyrometers:

API Model 303 - 0-300°F, 10 ohm
API Model 302 - 0-750°F, 10 ohm

Appendix C

TIRE-ROAD INTERFACE TESTS

C.1 TRACK SKID NUMBER

In order to determine the skid number of the Bendix Test Track and to assess the degree of change, if any, during the testing, a program was developed incorporating periodic sampling of the coefficient of friction on selected areas of the track. Reference readings of the skid number were made by the Michigan State Highway Department's skid trailer in accordance with ASTM procedure E-274 (omitting water delivery) and compared with surface coefficient measurements made with an instrumented passenger car equipped with ASTM E-249 tires. Several times during the testing program the surface was rechecked with this instrumented passenger car.

C.2 TEST SURFACE

All tests were conducted on either the high speed oval track or the large skid pad at the Bendix Automotive Development Center, New Carlisle, Indiana. For dry surface tests the oval track was used and wet tests were run on the large skid pad, with the exception of Vehicle 14, for which dry tests conducted on the approach to the skid pad for safety reasons.

The oval track consists of two straightaways, each 0.8 mile long and 36 ft (three lanes) wide. All stops are made on the inside (left-hand) lane on these straightaways which have an asphalt surface. The distance markers used as reference marks for the friction samples are located along both straight portions at 0.2 mile separation. The layout of the track and test point locations are indicated on the attached road map of the test site (Fig. C-1).

Wet tests were made on the large skid pad which has a surface coated with Jennite asphalt sealer and was wetted with the Bendix sprinkler truck. The treated surface is 80 ft wide by 800 ft long and testing was done on the long centerline. Skid numbers for this area were taken along each side of this centerline.

The skid pad approach used for Vehicle 14 has an initial width of 30 ft, widening to 80 ft, and a length of about 400 ft to the point where the Jennite treatment begins. It has a new (June 1970) asphalt surface and the area used for these tests does not have Jennite sealer.

TABLE C-1

COEFFICIENT OF FRICTION—BENDIX OVAL TRACK

Comparison of readings from MSHD skid trailer and U of M instrumented passenger car
Data from September 1969 and July 1970
Vehicle Velocity—40 mph
Track Condition—Dry Asphalt
Location—Inside (Left) Lane of East and West Straightaways
Tires—ASTM E-249

Test Point	μ Measured Sept. 1969			μ Measured July 1970		
	MSHD Trailer	UM Car	Variation, %	MSHD Trailer	UM Car	Variation, %
1	0.896	0.88	-1.8			
2	0.904	0.86	-5.1	0.884	0.84	-5.0
3	0.895	0.84	-6.1			
4	0.914	0.88	-3.7	0.872	0.83	-4.8
5	0.904	0.88	-2.7			
6	0.887	0.84	-5.3	0.866	0.82	-5.3
7	0.873	0.82	-6.0			
8	0.908	0.86	-5.3	0.882	0.78	-11.8
9	0.876	0.86	-1.8			
10	0.906	0.86	-5.3			
11	0.852	0.84	-1.4	0.844	0.80	-5.5
12	0.861	0.86	0			
13	0.875	0.86	-1.77	0.845	0.80	-5.6
14	0.839	0.83	-1.1			
15	0.861	0.86	0	0.858	0.80	-7.25
16	0.868	0.86	-0.9			
17	0.833	0.84	-6.5	0.867	0.79	-8.85
18	0.877	0.82				
Avg	0.879	0.85	-3.06%	0.865	0.81	-6.8%

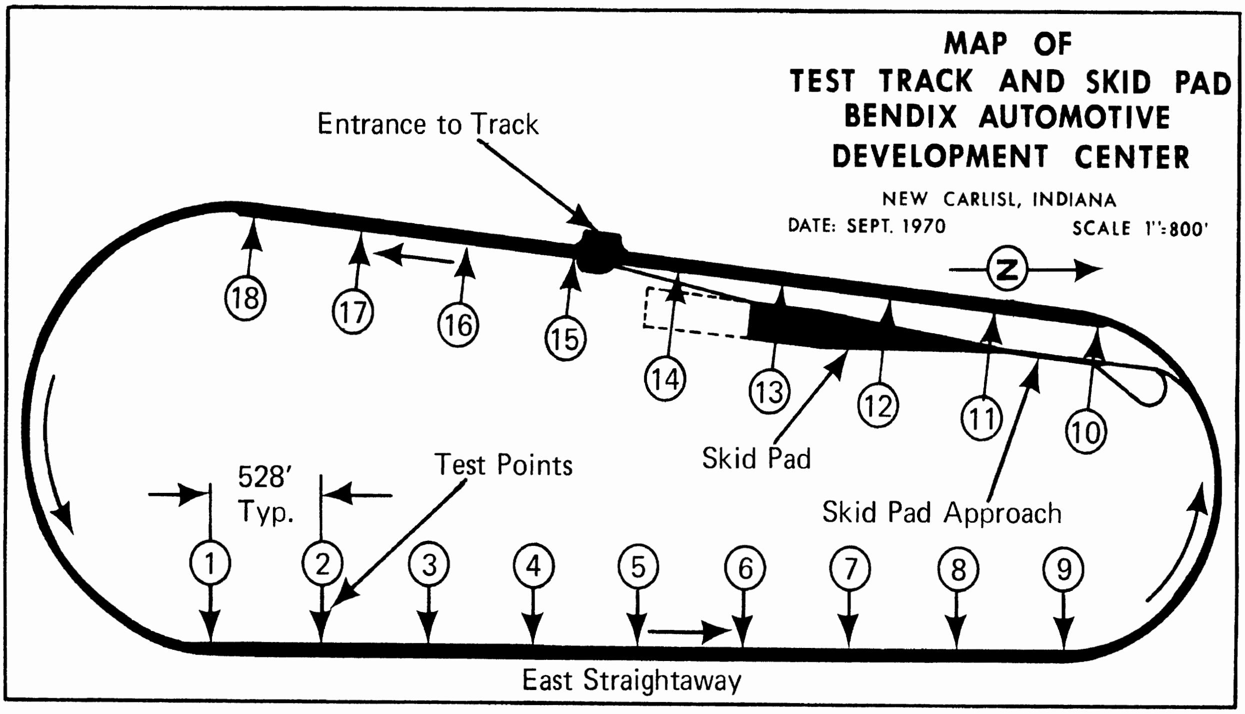


FIGURE C-1. TEST POINT LOCATIONS FOR TIRE-ROAD INTERFACE TESTS

C.3 PROCEDURE AND EQUIPMENT

C.3.1 MICHIGAN STATE HIGHWAY DEPARTMENT TRAILER. The Michigan State Highway Department skid trailer used for these tests is not built strictly in accordance with the specifications of ASTM Standard E-274, the major deviation being in the water spraying equipment, but this is of no consequence for our tests on dry pavement. The coefficient of friction is recorded directly on paper tape from a digital readout instrument.

C.3.2 UNIVERSITY OF MICHIGAN PASSENGER CAR - 247. The passenger car used for this program was a 1968 Plymouth Fury (U of M No. 247) in which a Bournes Model 602A accelerometer was mounted near the center of gravity, with the sensitive axis parallel to the center line of the vehicle. The instrument was calibrated to read ± 1 g with an accuracy of 3/4% of full scale. The accelerometer reading was displayed on a peak reading meter mounted beneath the dashboard where it could be monitored by both the driver and observer. The meter held the peak deceleration reading until manually reset. The car was equipped with four ASTM E-249 tires for this test.

C.3.3 PROCEDURE. The Skid trailer was used on the test site twice during the program: initially on the oval track, in September 1969, prior to start of the vehicle test program, and again in July 1970, prior to testing vehicles equipped with advanced systems, taking readings on both the oval track and the skid pad. In each case these tests were followed immediately by tests with the instrumented passenger car. The procedure with the passenger car, when testing the oval track, was to make several preliminary stops to warm up the tires and brakes, then make the recording stops in two circuits of the track, making brake snubs at alternate test points. On the skid pad the same procedure was followed, with all stops being made while traveling south. The peak deceleration was read directly from the meter in tenths of a g.

Three techniques of braking were investigated to find the best correlation with the skid trailer. They were: (a) locking a diagonal pair of wheels and bringing the vehicle to a full stop; (b) locking a diagonal pair of wheels momentarily ($\approx$1.0 sec) then releasing; and (c) locking all four wheels momentarily then releasing. The best agreement with skid trailer data was found with the third (c) method and that technique was used throughout the program. All stops were made from an initial velocity of 40 mph. These tests with the passenger car were repeated several times during the program, at least weekly, and more often during the first phase of the test program.

C.4 RESULTS

C.4.1 OVAL TRACK. The tire-road coefficient on the oval track (inside lane), as indicated by the skid trailer in 1969, ranged from 0.833 to 0.914 with an average of 0.879 for 18 test points. In July 1970, the same trailer gave readings that ranged from 0.844 to 0.884 with an average of 0.865 for eight test points. These data indicate the track coefficient changed very little over this period of time. Table C-1 shows data from the skid trailer compared with the readings taken with the passenger car.

From the first series of comparison stops, the test car was found to indicate 3 percent below the skid trailer and this correction was used thereafter for the dry track readings. The second set of skid tests with the Michigan State Highway Department's trailer showed slightly greater deviation between the two vehicles but the error was considered small enough to be ignored, and the use of a 3 percent correction factor was continued for dry surface tests. Ambient temperatures during these tests ranged between 37°F and 88°F. From these tests, the track coefficient was demonstrated to remain relatively constant throughout the test program. As shown in Fig. C-2, the average readings for Fall 1969 varied from 86.5 to 90.5 and for Summer 1970 from 82.5 to 86.5, the widely divergent readings being ignored.

While it may be expected that track temperature would affect the coefficient, driver application techniques seemed to have a much greater effect. The readings taken on the two hottest days gave average skid numbers of 68.8 (86°F) and 84.3 (88°F). These runs were made with two drivers who were both able to demonstrate consistent readings at all points on the track. One driver, the man who generated most of the skid number data during the summer of 1970, was able to produce skid numbers of 76 and 86 on successive passes at the same point by varying his rate of brake application only slightly. For this reason, this same driver was used to make a majority of test runs.

C.4.2 SKID PAD. When the skid trailer was operated on the skid pad, two watering techniques were used; self-watering by the skid trailer, and water applied by the Bendix tanker. The first watering method gave readings that ranged from 0.19 to 0.28 with an average of 0.23 for 10 test points. The second watering method, the method used by Bendix to wet the pad for testing, gave readings that ranged from a low of 0.17 to a high of 0.25 with an average of 0.22 for the same 10 points. There was some indication of possible hydroplaning when the water was supplied by the Bendix sprinkler truck. The results of these tests are shown in Table C-2.

The comparison runs made on the wet Jennite in July 1970 gave inconsistent correlation between the skid trailer and passenger car. The differences amounted to 80 percent at some points and there was no consistency in the results for the same points. The deceleration recorded is dependent on water depth, initial velocity, vehicle weight, and the driver's brake application technique. Since the surface of the skid pad has some undulations causing water pools of up to 3/16 in. deep, hydroplaning will be present in varying amounts. It is difficult to control the amount of water on the pad when high ambient temperatures and high wind velocities cause rapid evaporation. At these times, dry spots form rapidly while other spots retain heavy concen-

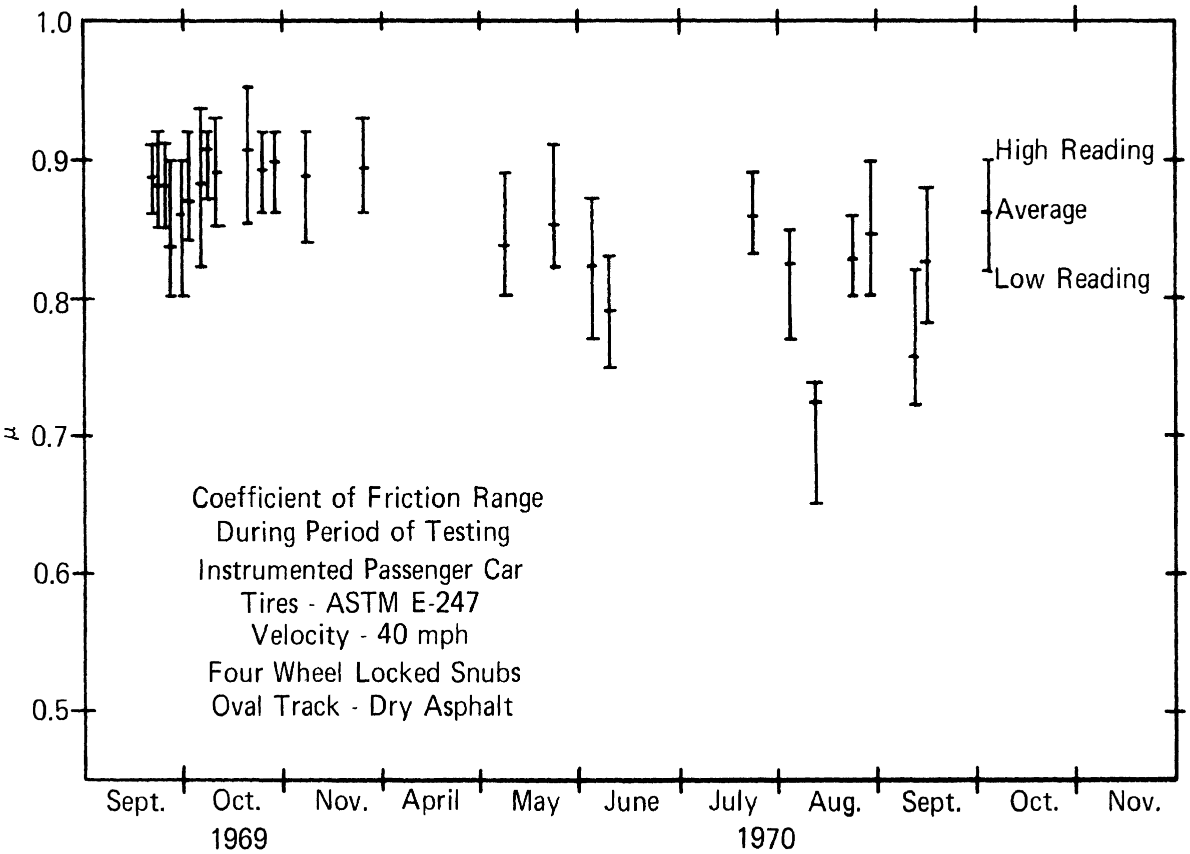


FIGURE C-2. COEFFICIENT OF FRICTION RANGE DURING PERIOD OF TESTING

TABLE C-2

COEFFICIENT OF FRICTION—BENDIX SKID PAD

Comparison of data from MSHD skid trailer
and U of M instrumented passenger car
Data from tests of July 1970
Vehicle Velocity—40 mph
Track Surface—Wet Jennite
Location—Large Skid Pad
Tires—ASTM E-249

Test Point	μ from MSHD Trailer Water Supply		μ from UM Car Run Number					
	Skid Trailer	Bendix Tanker	1	2	3	4	5	6
1	0.211	0.188	--	0.28	0.32	--	--	--
2	0.241, 0.193	0.181	0.30	0.26	0.38	0.30	0.32	0.42
3	0.198	0.217	--	--	--	--	--	--
4	0.200, 0.230	0.197	--	0.32	0.30	--	--	--
5	0.285, 0.240	0.131, 0.238	0.36	0.30	0.40	0.40	0.44	0.42
6	--	--	--	--	--	--	--	--
7	0.225	0.214	0.38	0.46	0.38	0.40	--	--
8	0.231	0.247	--	0.40	0.40	0.34	--	--
9	0.217	0.252	--	--	--	--	--	--
10	0.273	0.237	0.40	0.40	0.40	0.34	--	--
11	0.250	0.250	0.42	0.42	0.38	0.44	--	--
Avg	0.230	0.214	0.37	0.36	0.37	0.37	0.38	0.42

trations of water.

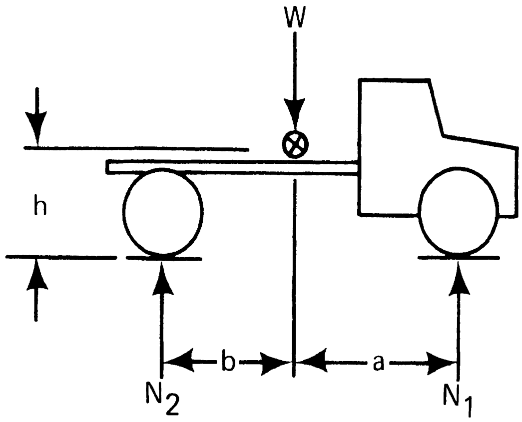
C.4.3 SKID PAD APPROACH. Since the use of the skid pad approach area for dry stops was not anticipated at the time the Michigan State Highway Department's skid trailer was at BADC, a full series of checks on this area was not made. Only two samples of this surface were taken giving a μ of 0.88 and 0.86. These meager data indicate the surface is much the same as the oval track (average of 0.865 on the same date). Two measurements made with the passenger car at that time gave coefficients of 0.80 and 0.82. It should be noted that this 7 percent difference is about the same as the discrepancy noted for the comparison tests made on the oval track on that date.

Concurrently with the testing of Vehicle 14, the passenger car was used to take additional coefficient of friction data on the area of the skid pad approach which was being used for the dry tests. While the data cannot be compared with readings taken by the Michigan State Highway Department's trailer, it can be compared with other readings taken with this passenger car on the oval track. Three snubs were made at each of three spots on the asphalt, producing readings that ranged from 0.80 to 0.86 with an average of 0.81. If we apply the correction factor determined from the July comparison tests (7%), this would give an average skid number of 87, essentially the same as the oval track. To compare this data with the measurements made with this sedan during previous testing, a correction factor of 103 should be used. This gives a skid number of 83.

C.5 COEFFICIENT OF FRICTION BETWEEN TRUCK TIRES AND TRACK SURFACE

In November of 1970, some tests were conducted to determine the coefficient of friction between the truck tires used on Vehicles 11 and 12 (advanced systems) and the three different test surfaces at BADC. Vehicle 11, a Ford F-1000 flat bed truck, equipped with disk brakes was used for these tests. The tires used were Remington Premium Highway Universal, 10 x 20, 12 ply nylon, tube type, load range F. Two types of tests were conducted: locked wheel stops and tow bar with wheels locked.

C.5.1 LOCKED WHEEL STOPS, FRONT BRAKES ONLY. These stops were made from nominal speeds of 10, 20, 30, 40, 50, and 60 mph, on the dry track and speeds of 10, 20, 30, and 40 on the wet Jennite. Three stops were made from each speed with the front wheels locked (rear brakes disconnected). During each stop, velocity (fifth wheel), deceleration, brake-line pressure, and front wheel lock up were recorded. The coefficient of friction, μ, was calculated (using the deceleration, vehicle geometry, and static loads), at the point of initial wheel lock up and at each 10 mph velocity increment as the vehicle came to a stop (Fig. C-3). The results of this test are shown in the graphs for each track area tested (Figs. C-4, C-5, and C-6).



h = 36 in
a+b = 170.25 in
b = 79.83 in
W = 13650 lb

$$\mu = \frac{\text{Brake Force}}{\text{Normal Force } (N_1)}$$

$$\text{Brake Force} = \frac{W}{g}\ddot{x} = \frac{13650}{32.2}\ddot{x}$$

$$\text{Normal Force} = \left(\frac{b}{a+b}\right)W + \left(\frac{h}{a+b}\right)\frac{W}{g}\ddot{x}$$

$$\therefore \mu = \frac{\frac{13650}{32.2}\ddot{x}}{\left(\frac{79.83}{170.25}\right)13650 + \left(\frac{36}{170.25}\right)\left(\frac{13650}{32.2}\right)\ddot{x}}$$

FIGURE C-3. CALCULATION OF LOCKED-WHEEL TIRE-ROAD FRICTION COEFFICIENT

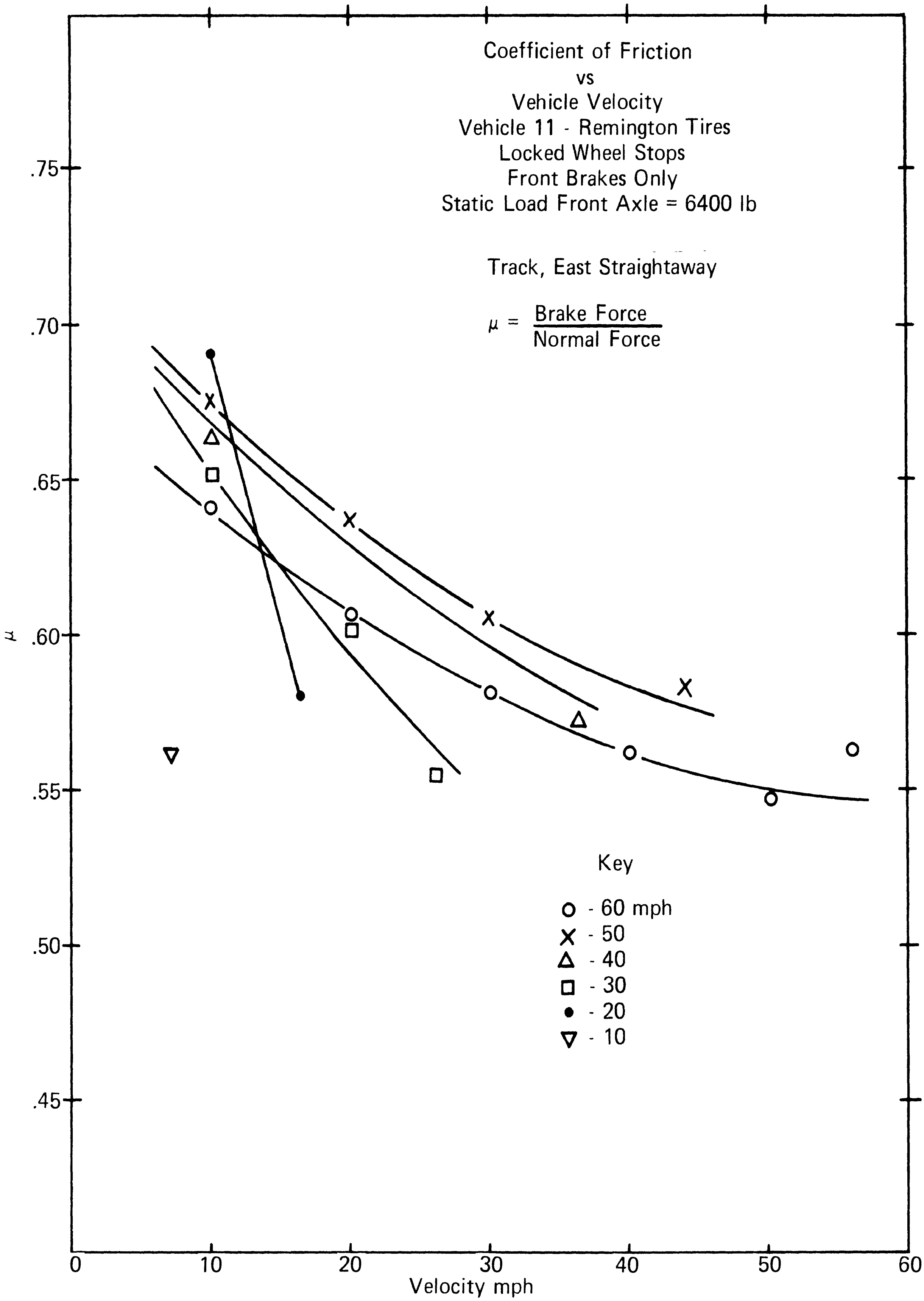


FIGURE C-4. LOCKED-WHEEL COEFFICIENT OF FRICTION VS VEHICLE VELOCITY, EAST STRAIGHTAWAY

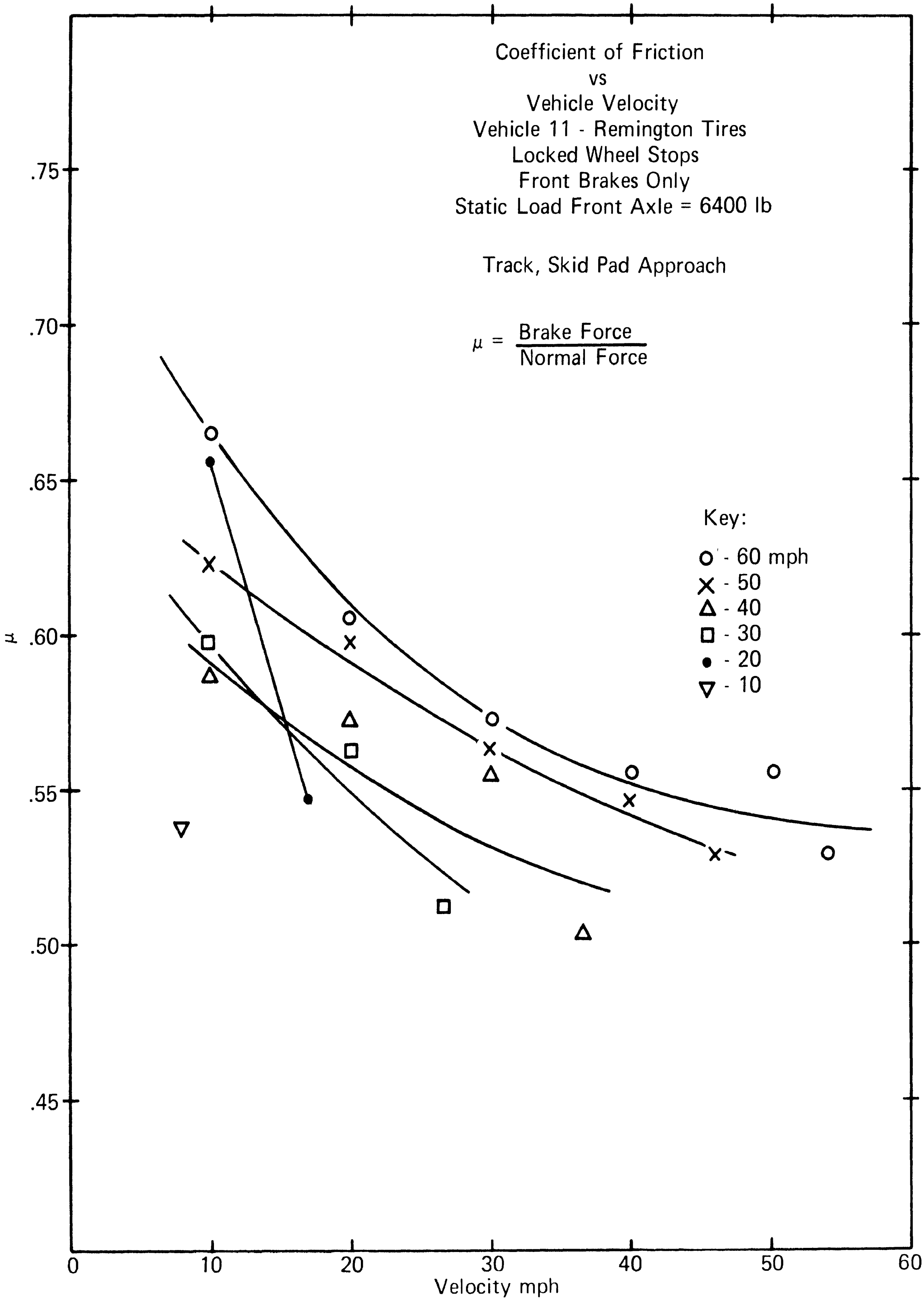


FIGURE C-5. LOCKED-WHEEL COEFFICIENT OF FRICTION VS VEHICLE VELOCITY, SKID PAD APPROACH

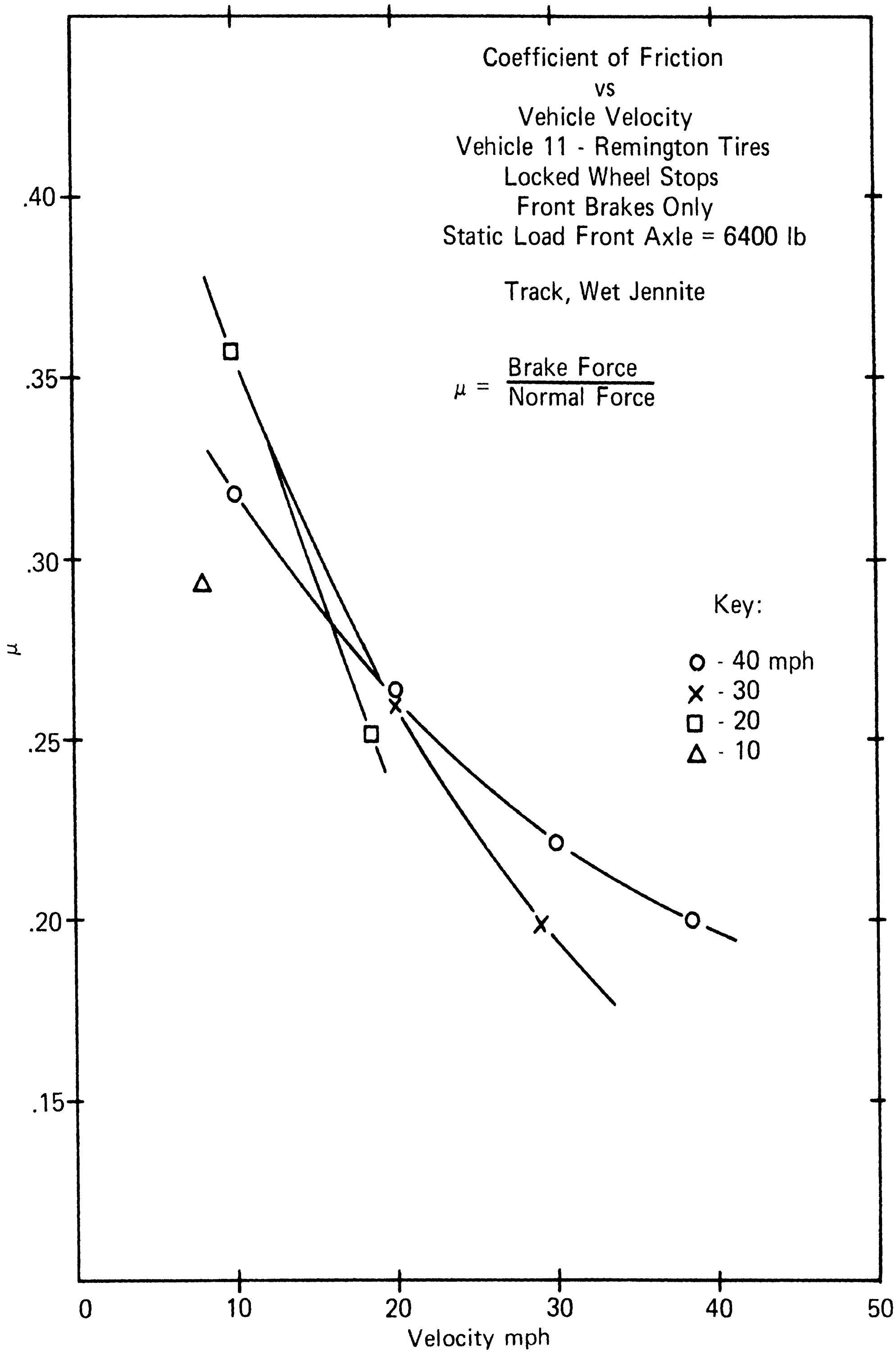
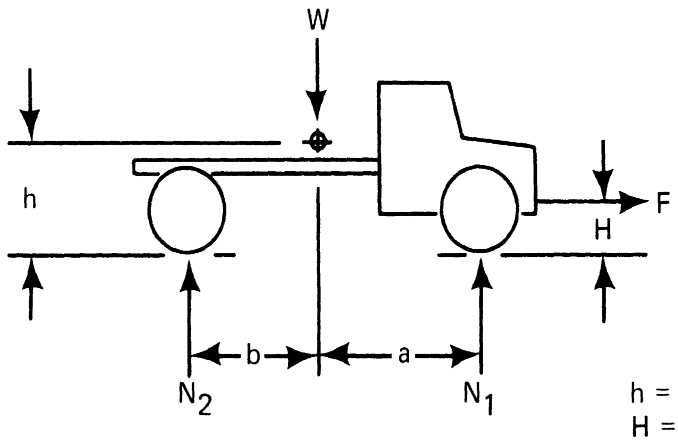


FIGURE C-6. LOCKED-WHEEL COEFFICIENT OF FRICTION VS VEHICLE VELOCITY, WET SEALED SURFACE OF SKID PAD

C.5.2 TOW BAR TEST, FRONT WHEELS LOCKED. For this test, the vehicle was towed over each test site using the instrumented tow bar, which had been used in the brake rating tests. Brake applications were made, locking the front wheels (rear brakes were disconnected) while maintaining speed with the towing vehicle. This test was repeated at initial velocities of 10, 20, 30, and 40 mph, the highest speed which could be maintained by the towing vehicle. The test was repeated three times at each speed. During the brake application, continuous recordings were made of velocity (fifth wheel), deceleration, brake-line pressure, wheel lock up, and tow bar load. Two values of the coefficient of friction, μ, were calculated (for each brake application), using the deceleration (+ of -), tow bar force, vehicle geometry, and static loading (Fig. C-7). The peak value represents maximum tow bar load reached just after wheel lock up. The steady-state value represents that level of tow bar load maintained throughout the remainder of the brake application. These quantities are shown on the bar graphs for each test site (Figs. C-8, C-9, and C-10).

The data from both these tests show an increase in friction coefficient with decreasing velocity although the slopes of the curves do not agree, the tow bar test giving a greater range between high and low speeds. The tests also show the skid pad approach road to have a lower coefficient than the East straightaway, although the difference is quite small, particularly at the higher speeds, as shown on Fig. C-11. The data from the instrumented passenger car also indicate very little difference between these areas at a speed of 40 mph with ASTM tires.



h = 36 in.
H = 28.75 in.
b = 79.83 in.
a+b = 170.25 in.
W = 13650 lb
F = Tow Bar Force

$$\mu = \frac{\text{Tow bar force - Rolling Resistance}}{\text{Normal force } (N_1)}$$

$$N_1 = \left(\frac{b}{a+b}\right) W + \left(\frac{h}{a+b}\right) \frac{W}{g} \ddot{x} + \frac{HF}{a+b}$$

$$\therefore \mu = \frac{F - R.R.}{\left(\frac{79.83}{170.25}\right) 13650 + \left(\frac{36}{170.25}\right)\left(\frac{13650}{32.2}\right) \ddot{x} + \frac{(28.75)\ F}{170.25}}$$

FIGURE C-7. CALCULATIONS FOR TIRE-ROAD INTERFACE COEFFICIENT OF FRICTION, TOWING TESTS

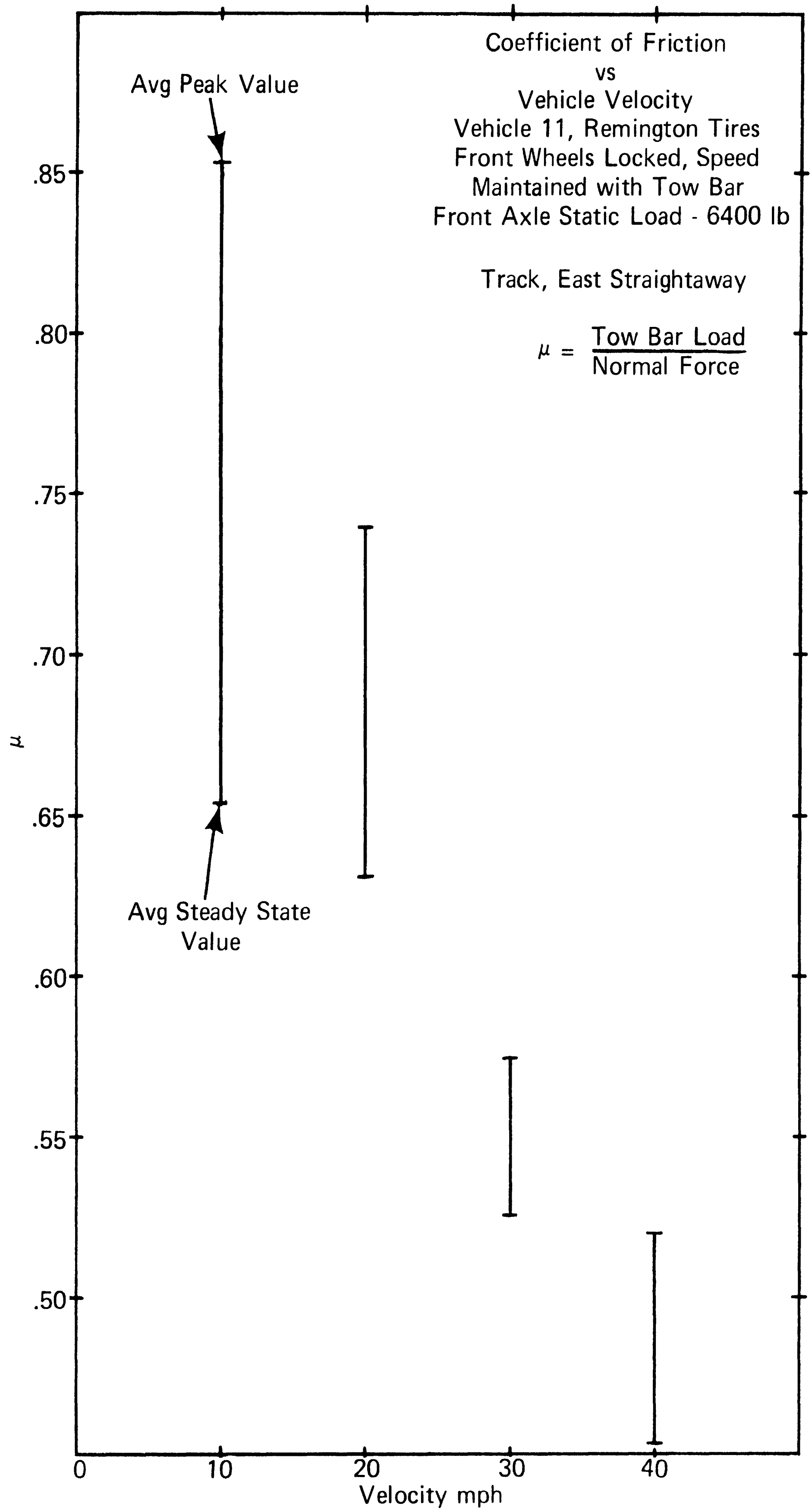


FIGURE C-8. PEAK AND SLIDING COEFFICIENT OF FRICTION, EAST STRAIGHTAWAY

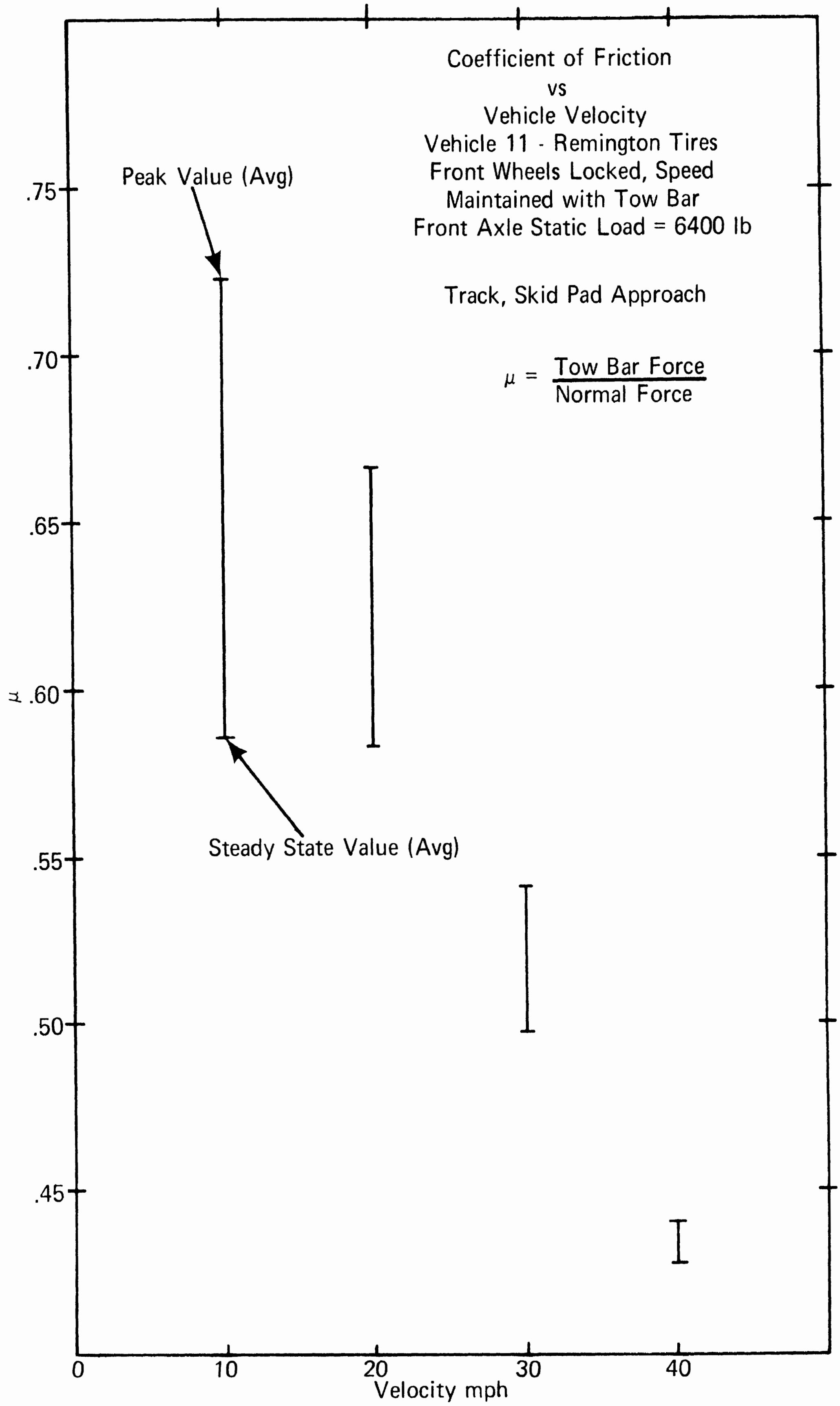


FIGURE C-9. PEAK AND SLIDING COEFFICIENT OF FRICTION, SKID PAD APPROACH

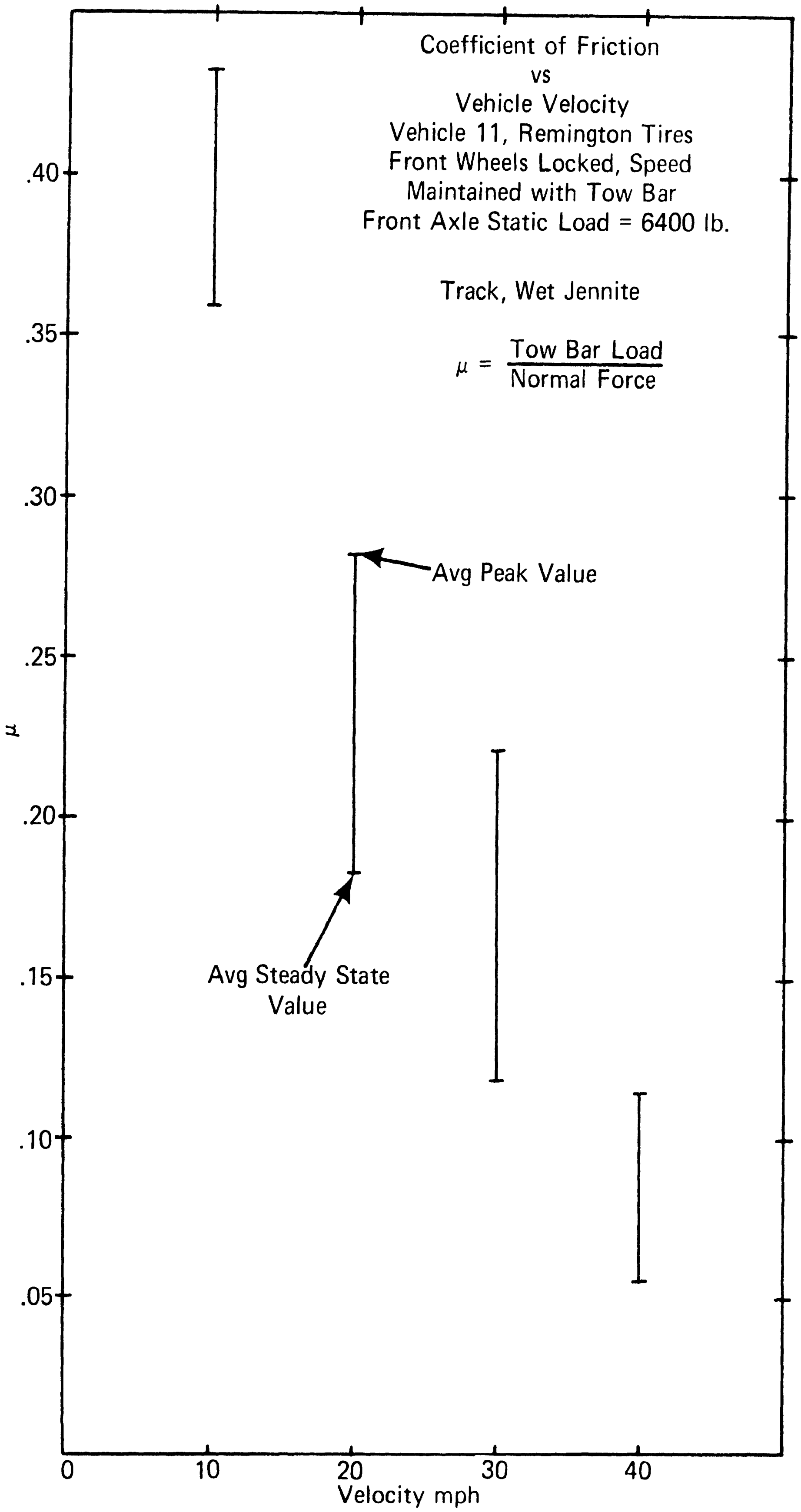


FIGURE C-10. PEAK AND SLIDING COEFFICIENT OF FRICTION, WET SEALED SURFACE OF SKID PAD

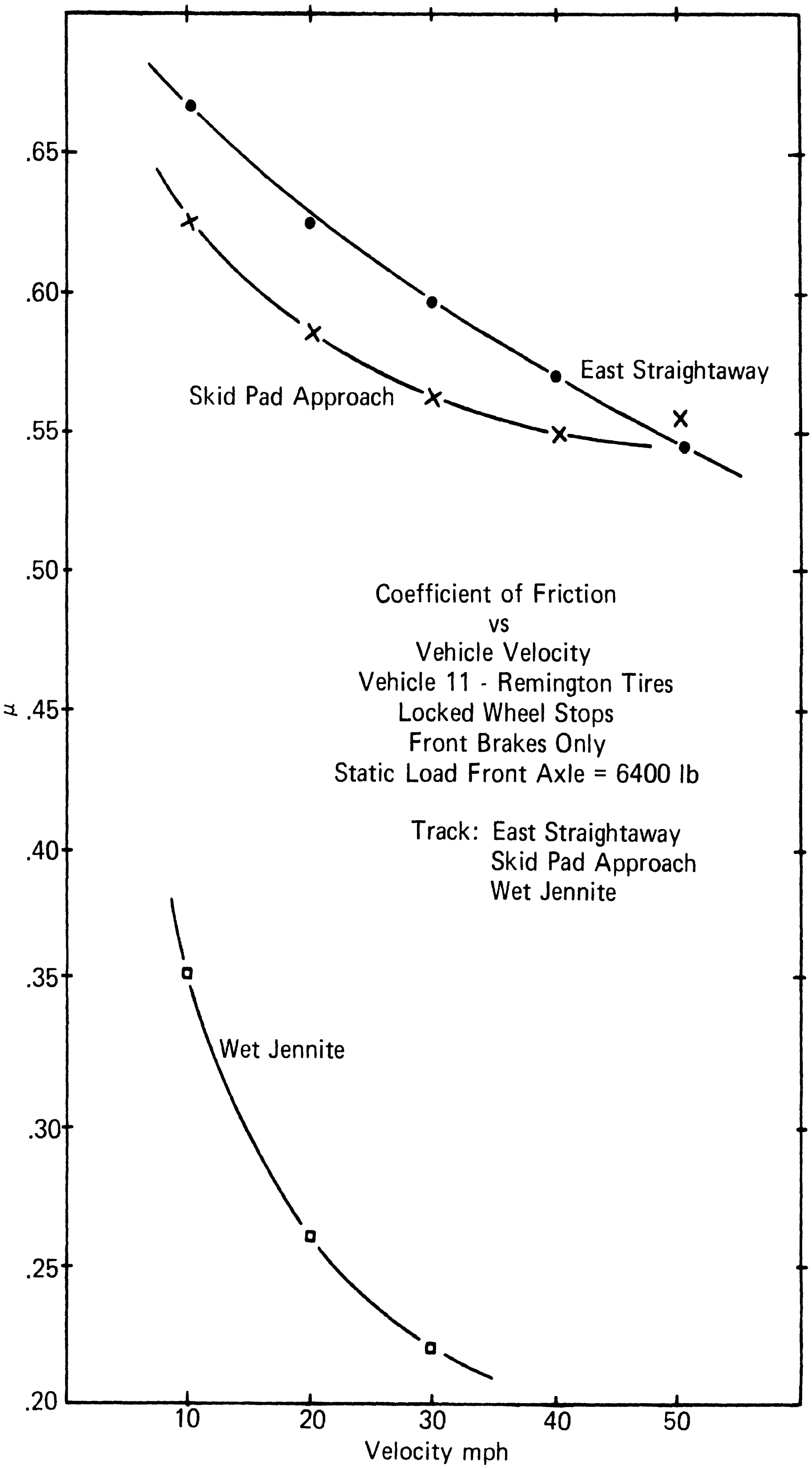


FIGURE C-11. AVERAGED LOCKED-WHEEL COEFFICIENTS

Appendix D

TRUCK AND TRACTOR-TRAILER BRAKING PERFORMANCE MODEL

The model described in this appendix represents either a 2-axle truck or tractor, or a 3-axle tractor-trailer combination Motions are constrained to the plane of symmetry (vertical plane). Specifically, the wheels can bounce and spin, the chassis can heave and pitch, and the vehicle can accelerate (decelerate) in straight line motion. The braking system is modeled such that variable time lags and delays in torque response can be introduced Any desired brake force distribution can be specified. The model is so devised that changes in vehicle geometry, suspension characteristics, loading conditions, and tire-road interface coefficients are easily introduced.

D.1 MECHANIZATION

The model was mechanized on the Applied Dynamics AD-4 IBM-1130 Hybrid computer system at the Highway Safety Research Institute.* The vehicle equations of motion and the dynamics of the braking system were modeled on the analog computer, while the digital computer was used to initialize the analog program, to set the coefficient devices, and to run a static check (verification of the voltage outputs of the analog program).

D.2 THE MODEL

The model has eleven degrees of freedom, which are listed in Table D-1, along with the program variable representing each degree of freedom. To determine the values of these variables as functions of time, the eleven differential equations of motion listed below are solved simultaneously:

Tractor Heave

$$M\ddot{Z} = -(K1)(S1) - (C1)(\dot{S1}) - (CF1) - (K2)(S2) - (C2)(\dot{S2})$$

$$- (CF2) - V \qquad \text{(D-1)}$$

*The hybrid computer facility is described in SAE Paper No. 700154, "A Hybrid Computer System for the Simulation of Vehicle Dynamics," by Ray W Murphy.

TABLE D-1

DEGREES OF FREEDOM, BRAKING PERFORMANCE MODEL

Program Variable	Description
X	vehicle forward displacement
Z	vertical displacement of CG of truck or tractor
θ	pitch angle of truck or tractor
Z1	vertical displacement of CG of trailer
$\theta 1$	pitch angle of trailer
ZS1	vertical displacement of tractor front wheels
ZS2	vertical displacement of tractor rear wheels
ZS3	vertical displacement of trailer wheels
$\phi 1$	angular position of tractor front wheels
$\phi 2$	angular position of tractor rear wheels
$\phi 3$	angular position of trailer wheels

Tractor Pitch

$$J\ddot{\theta} = -A1[(K1)(S1) + (C1)(\dot{S}1) + (CF1)] + A2[(K2)(S2) + (C2)(\dot{S}2) + (CF2)] + (A2-B)(V) - (D)(H) - t_1 - t_2 - L1(\delta 1 + S1) - L2(\delta 2 + S2) \quad (D-2)$$

Trailer Heave

$$(M1)(\ddot{Z}1) = V - (K3)(S3) - (CF3) \quad (D-3)$$

Trailer Pitch

$$(J1)(\ddot{\theta}1) = V(A3) + (A4)\ [(K3)(S3) + (CF3)] - (H)(D1) - t_3 - L3\ (\delta 3 + S3) \quad (D-4)$$

Vehicle Forward Motion

$$(M + M1 + MS1 + MS2 + MS3)\ddot{X} = -(BF1 + BF2 + BF3) \quad (D-5)$$

Wheel Hop

$$(MS1)(\ddot{Z}S1) = (K1)(S1) + (C1)(\dot{S}1) + (CF1) + (K1T)(ZS1) \quad (D-6)$$

$$(MS2)(\ddot{Z}S2) = (K2)(S2) + (C2)(\dot{S}2) + (CF2) + (K2T)(ZS2) \quad (D-7)$$

$$(MS3)(\ddot{Z}S3) = (K3)(S3) + (CF3) + (K3T)(ZS3) \quad (D-8)$$

Wheel Rotation

$$(JS1)(\ddot{\phi}1) = (BF1)(\alpha 1 + ZS1) - t_1 \quad (D-9)$$

$$(JS2)(\ddot{\phi}2) = (BF2)(\alpha 2 + ZS2) - t_2 \quad (D-10)$$

$$(JS3)(\ddot{\phi}3) = (BF3)(\alpha 3 + ZS3) - t_3 \quad (D-11)$$

The terms used in these equations are defined in Table D-2. Figure D-1 defines the vehicle geometry and coordinate system used to devise the equations of motion. Ancillary equations defining intermediate variables are given below:

Suspension Deflections

$$S1 = Z - (ZS1) + (A1)\theta \qquad (D\text{-}12)$$

$$S2 = Z - (ZS2) - (A2)\theta \qquad (D\text{-}13)$$

$$S3 = Z1 - (ZS3) - (A4)\theta 1 \qquad (D\text{-}14)$$

Brake Forces

$$BF1 = (\mu 1)N1 \qquad (D\text{-}15)$$

$$BF2 = (\mu 2)N2 \qquad (D\text{-}16)$$

$$BF3 = (\mu 3)N3 \qquad (D\text{-}17)$$

Horizontal Forces Acting on Sprung Masses

$$L1 = BF1 + (MS1)\ddot{X} \qquad (D\text{-}18)$$

$$L2 = BF2 + (MS2)\ddot{X} \qquad (D\text{-}19)$$

$$L3 = BF3 + (MS3)\ddot{X} \qquad (D\text{-}20)$$

Horizontal Force At 5th Wheel

$$H = -(M1)\ddot{X} - L3 \qquad (D\text{-}21)$$

Vertical Force At 5th Wheel

$$V = KF[Z - (A2-B)\theta - Z1 - (A3)(\theta 1)] \qquad (D\text{-}22)$$

Normal Forces On Tires

$$N1 = N1S - (ZS1 - R1)(K1T) \qquad (D\text{-}23)$$

$$N2 = N2S - (ZS2 - R2)(K2T) \qquad (D\text{-}24)$$

$$N3 = N3S - (ZS3 - R3)(K3T) \qquad (D\text{-}25)$$

Tire Deflections

$$DR1 = ZS1 - R1 \quad \text{(D-26)}$$

$$DR2 = ZS2 - R2 \quad \text{(D-27)}$$

$$DR3 = ZS3 - R3 \quad \text{(D-28)}$$

Wheel Slip

$$i1 = 1 - \frac{(\dot{\phi}1)(DR1 + \alpha 1)}{\dot{X}} \quad \text{(D-29)}$$

$$i2 = 1 - \frac{(\dot{\phi}2)(DR2 + \alpha 2)}{\dot{X}} \quad \text{(D-30)}$$

$$i3 = 1 - \frac{(\dot{\phi}3)(DR3 + \alpha 3)}{\dot{X}} \quad \text{(D-31)}$$

Tire-Road Interface Coefficient*

$$\mu 1 = f(i_1) \quad \text{(D-32)}$$

$$\mu 2 = f(i_2) \quad \text{(D-33)}$$

$$\mu 3 = f(i_3) \quad \text{(D-34)}$$

The functional relationships of the various parts of the dynamic model are shown in block diagram form in Fig. D-2.

D.3 VEHICLE PARAMETERS

Forty-six parameters are necessary to describe the vehicle geometry, loading, suspension, brake system, and tire-road interface characteristics for a tractor-semitrailer. These parameters are identified in Table D-3. The numerical values listed are those used in the simulation of Vehicle 6, the Ford F-1000 tractor in combination with Trailmobile 35-foot van trailer.

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*The generation of μ as a function of wheel slip was accomplished on stored program diode function generators. The input-output relationships for three different simulated road surfaces is given in Fig. 127.

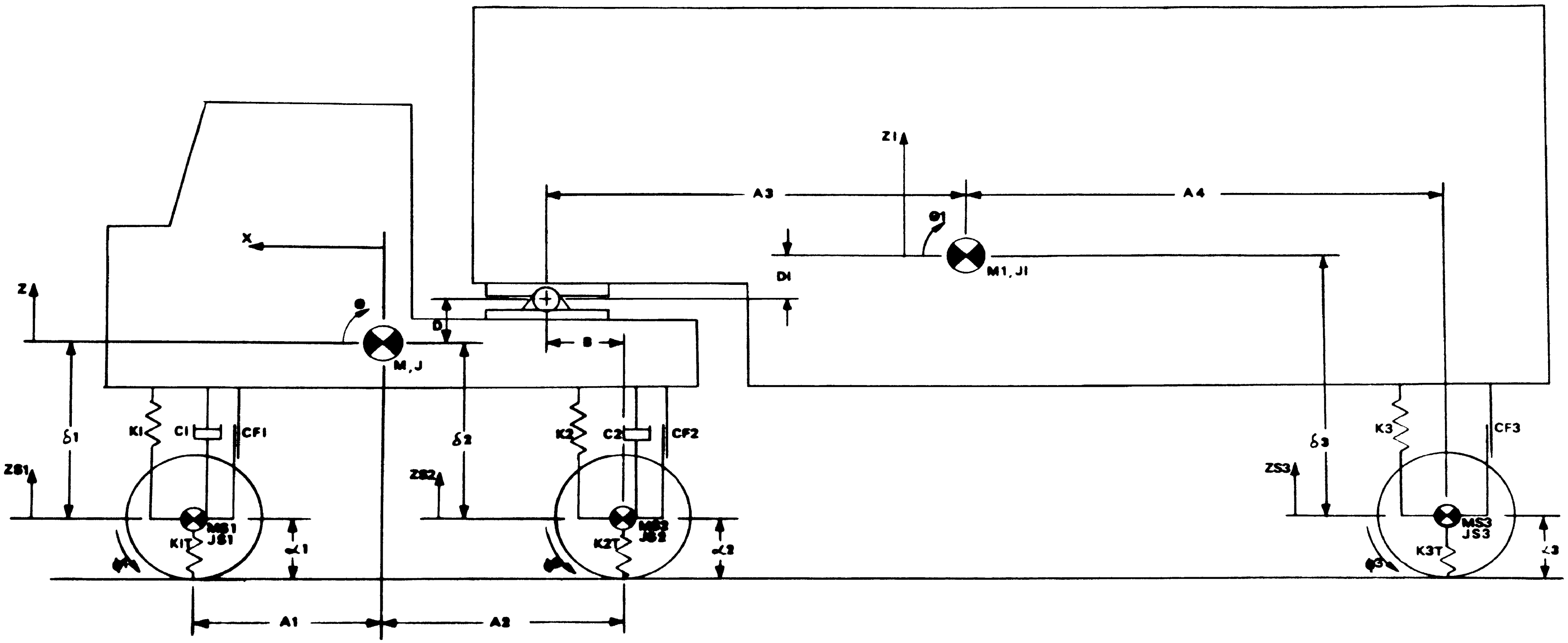

FIGURE D-1. TRACTOR-TRAILER GEOMETRY

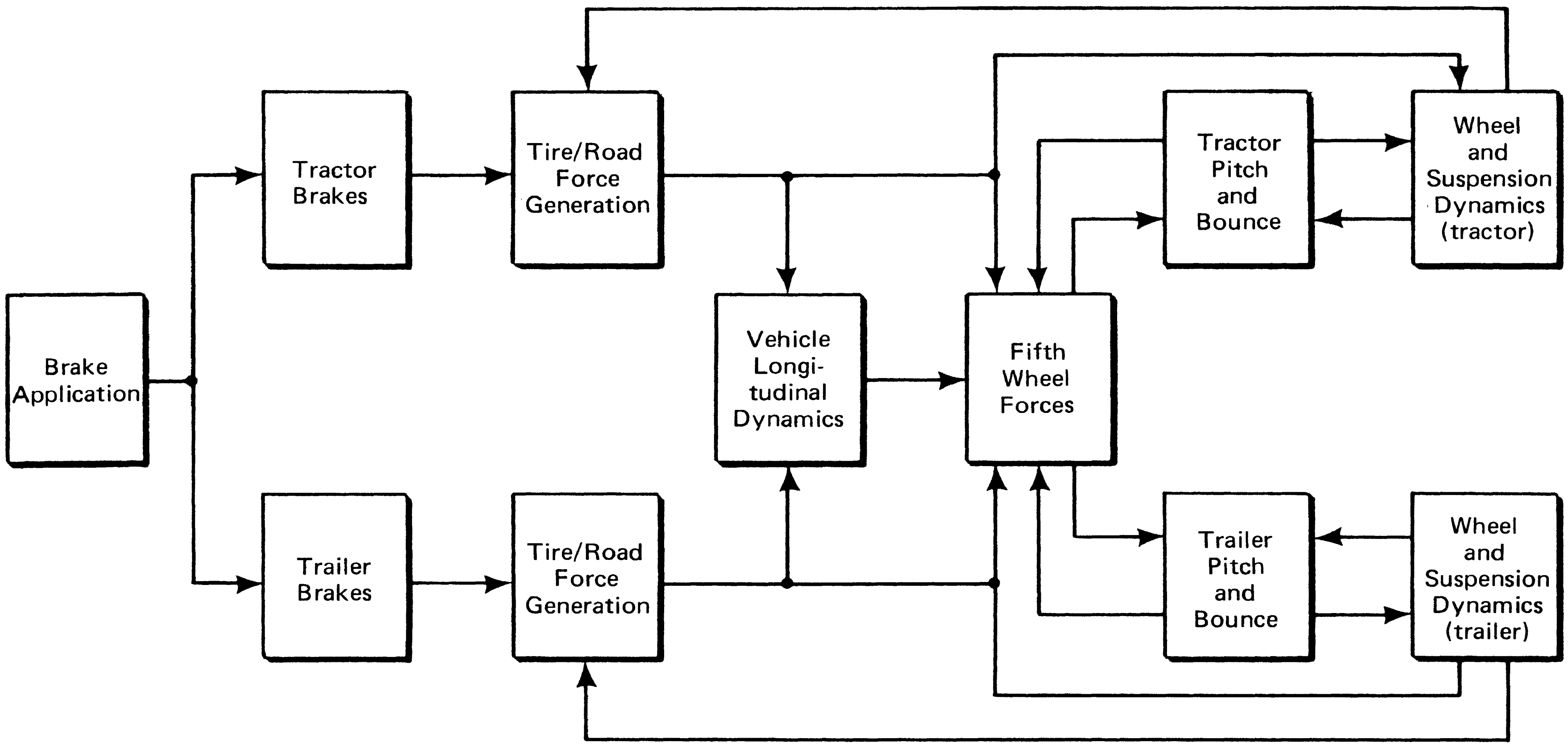

FIGURE D-2. SIMULATION DIAGRAM, TRACTOR-TRAILER BRAKING PERFORMANCE MODEL

TABLE D-2

GLOSSARY OF TERMS

Program Variable	Description
A1	horizontal distance from tractor CG to MS1
A2	horizontal distance from tractor CG to MS2
A3	horizontal distance from trailer CG to fifth wheel
A4	horizontal distance from trailer CG to MS3
B	horizontal distance from fifth wheel to MS2
BF1	brake force of road on wheel 1
BF2	brake force of road on wheel 2
BF3	brake force of road on wheel 3
C1	viscous damping in suspension 1
C2	viscous damping in suspension 2
CF1	maximum Coulomb friction in suspension 1
CF2	maximum Coulomb friction in suspension 2
CF3	maximum Coulomb friction in suspension 3
D	vertical distance from fifth wheel connection to tractor CG
D1	vertical distance from fifth wheel connection to trailer CG
DR1	deflection of tire spring 1
DR2	deflection of tire spring 2
DR3	deflection of tire spring 3
GVW	gross vehicle weight

TABLE D-2 (Continued)

GLOSSARY OF TERMS

Program Variable	Description
H	horizontal force between tractor and trailer, compression is positive
i1	coefficient of slip for tire 1
i2	coefficient of slip for tire 2
i3	coefficient of slip for tire 3
J	pitch moment of inertia of tractor
JS1	roll moment of inertia of wheel 1
JS2	roll moment of inertia of wheel 2
JS3	roll moment of inertia of wheel 3
J1	pitch moment of inertia of trailer
KF	vertical spring rate of fifth wheel
K1	spring rate of suspension 1
K1T	spring rate of tire 1
K2	spring rate of suspension 2
K2T	spring rate of tire 2
K3	spring rate of suspension 3
K3T	spring rate of tire 3
L1	horizontal force of tractor on wheel 1 forward is positive
L2	horizontal force of tractor on wheel 2
L3	horizontal force of tractor on wheel 3

TABLE D-2 (Continued)

GLOSSARY OF TERMS

Program Variable	Description
M	sprung mass of tractor
MS1	mass of suspension 1
MS2	mass of suspension 2
MS3	mass of suspension 3
M1	sprung mass of trailer
N1	normal force on tire 1
N2	normal force on tire 2
N3	normal force on tire 3
N1S	static loads on tire 1
N2S	static loads on tire 2
N3S	static loads on tire 3
R1	road input to tire 1
R2	road input to tire 2
R3	road input to tire 3
S1	deflection of suspension 1
S2	deflection of suspension 2
S3	deflection of suspension 3
T1	attempted torque input to wheel 1
t_1	actual torque input to wheel 1; $t_1 = T_1$ for rolling wheel, $t_1 = BF_1 \cdot \delta_1$ for locked wheel
T2	attempted torque input to wheel 2

TABLE D-2 (Continued)

GLOSSARY OF TERMS

Program Variable	Description
t_2	actual torque input to wheel 2
T3	attempted torque input to wheel 3
t_3	actual torque input to wheel 3
V	force in spring at fifth wheel, compression is positive
Z	vertical position of tractor—static position is Z = 0
Z1	vertical position of trailer
ZS1	vertical position of MS1
ZS2	vertical position of MS2
ZS3	vertical position of MS3
α_1	static vertical distance from MS1 to road
α_2	static vertical distance from MS2 to road
α_3	static vertical distance from MS3 to road
δ_1	static vertical distance from M to MS1
δ_2	static vertical distance from M to MS2
δ_3	static vertical distance from M to MS3
θ	pitch angle of tractor—front end up is positive
θ_1	pitch angle of trailer—front end up is positive
μ_1	coefficient of friction between tire 1 and road

TABLE D-2 (Concluded)

GLOSSARY OF TERMS

Program Variable	Description
μ_2	coefficient of friction between tire 2 and road
μ_3	coefficient of friction between tire 3 and road
ϕ_1	roll angle of wheel 1
ϕ_2	roll angle of wheel 2
ϕ_3	roll angle of wheel 3
$(\dot{\ })$ =	$d/dt\ (\ )$
$(\ddot{\ })$ =	$d^2/dt^2\ (\ )$

TABLE D-3

VEHICLE PARAMETERS AND TYPICAL VALUES

Parameter No.	Parameter Symbol	Description	Typical Value
1	W	Tractor sprung weight	3,736 lb
2	J	Tractor polar moment of inertia	2,315 SLUG-ft^2
3	WS1	Front unsprung weight	794 lb
4	JS1	Combined polar moment of front wheels	18 SLUG-ft^2
5	WS2	Rear unsprung weight	1,785 lb
6	JS2	Combined polar moment of rear wheels	41.6 SLUG-ft^2
7	A1	Horizontal distance from tractor CG to front wheels	5.0 ft
8	A2	Horizontal distance from tractor CG to rear wheels	7.0 ft
9	B	Horizontal distance from fifth wheel to tractor rear wheels	1.925 ft
10	D	Vertical distance from fifth wheel to tractor CG	1.0 ft
11	K1	Spring rate, front suspension	48,000 lb/ft
12	C1	Viscous damping, front suspension	1,000 lb-sec/ft
13	K1T	Spring constant, front tires	120,000 lb/ft
14	α1	Initial distance, center of front wheels to ground	1.64 ft
15	δ1	Initial distance, center of front wheel to tractor CG	1.32 ft
16	CF1	Maximum Coulomb friction, front suspension	700 lb

TABLE D-3 (Continued)

VEHICLE PARAMETERS AND TYPICAL VALUES

Parameter No.	Parameter Symbol	Description	Typical Value
17	K2	Spring rate, rear suspension	60,000 lb/ft
18	C2	Viscous damping, rear suspension	0
19	K2T	Spring constant, rear tires	240,000 lb/ft
20	$\alpha 2$	Initial distance, center of rear wheel to ground	1.64 ft
21	$\delta 2$	Initial distance, center of rear wheel to tractor CG	1.32 ft
22	CF2	Maximum Coulomb friction, rear suspension	1,800 lb
23	D1	Vertical distance from fifth wheel connection to trailer CG	1.81 ft
24	A3	Horizontal distance from fifth wheel to trailer CG	13.58 ft
25	A4	Horizontal distance from trailer CG to trailer rear axle	11.38 ft
26	W1	Trailer and load sprung weight	34,000 lb
27	J1	Trailer and load polar moment of inertia	52,000 SLUG-ft^2
28	WS3	Trailer unsprung weight	1,417 lb
29	JS3	Combined polar moment of trailer wheels	41.6 SLUG-ft^2
30	K3	Spring rate, trailer suspension	72,000 lb/ft
31	CF3	Maximum Coulomb friction, trailer suspension	1,800 lb
32	K3T	Spring rate, trailer tires	240,000 lb/ft

TABLE D-3 (Concluded)

VEHICLE PARAMETERS AND TYPICAL VALUES

Parameter No.	Parameter Symbol	Description	Typical Value
33	$\alpha 3$	Initial distance, center of trailer wheel to ground	1.64 ft
34	$\delta 3$	Initial distance center of trailer wheel to trailer CG	4.49 ft
35	TRAIL	Logical variables { =1.0 if single vehicle, =2.0 if tractor-trailer	2.0
36	μ_1LOCK	Locked wheel coefficient, front wheels	0.7
37	μ_2LOCK	Locked wheel coefficient, rear wheels	0.7
38	μ_3LOCK	Locked wheel coefficient, trailer wheels	0.7
39	PERCF	Percent of total tractor braking effort on front wheels	39
40	POT 260	Total torque applied to tractor brakes divided by 50,000 ft-lb	0.2157
41	POT 262	Total torque applied to trailer brakes divided by 40,000 ft-lb	0.2304
42	$\tau 1$	Time constant of front brakes	0.23 sec
43	$\tau 2$	Time constant of rear brakes	0.23 sec
44	$\tau 3$	Time constant of trailer brakes	0.185 sec
45	DELAY	Transport delay between application of brakes and actuation of trailer brakes	0.15 sec
46	VO	Initial velocity	88 ft/sec

Appendix E

BRAKING PERFORMANCE DIAGRAM CALCULATION PROGRAM

The digital computer program described in this appendix was devised to facilitate the making of the calculations necessary to construct the braking performance diagrams given in Section 4.4, using the set of equations described in Section 4.2.

The program consists of five steps:

(1) Input: vehicle, brake data, loading conditions, etc., are entered into the program.

(2) Initialization: brake-line pressure is set to a given value, i.e., $p_1 = 5$ psi.

(3) Calculations: necessary calculations including brake force, decelerations, and dynamic axle loads are made.

(4) Output: results from calculations are printed.

(5) Increment/Stop: if line pressure is less than maximum value, it is incremented and another set of calculations made. Otherwise the program is terminated.

Table E-1 details each program step for the version of the program used to construct the vehicle performance diagram for Vehicle 12.

Table E-2 gives the typical input and output data for the program.

TABLE E-1

BRAKE PERFORMANCE DIAGRAM CALCULATION
PROGRAM FOR 3-S2 TRACTOR-TRAILER

A. INPUT

1. Vehicle Geometric and Loading Parameters
2. Initial Velocity
3. Tire/Road Interface Coefficients
4. Brake Lining Data
5. Brake Response Time and Push Out Pressures
6. Brake Data
   a. Front brakes: chamber size, wedge angle, dimensions, mechanical efficiency
   b. Tractor rear brakes: chamber size, cam radius, slack adjuster length, dimensions, mechanical efficiency
   c. Trailer brakes: chamber size, cam radius, slack adjuster length, dimensions, mechanical efficiency

B. INITIALIZE BRAKE LINE PRESSURE

C. CALCULATE

1. Pressure at Each Brake (p_i)
2. Effective Lining Coefficients $\mu_i = f(p_i)$, i = 1 to 5
3. Brake Factors (BF_i), i = 1 to 5
4. Brake Force (F_i), i = 1 to 5
5. If $F_i > \mu N_i$, Set $F_i = \mu N_i$, Otherwise Continue, i = 1 to 5
6. Sum Brake Forces
7. Deceleration
8. Stopping Distance
9. Normal Wheel Loads Due to Load Transfer, Including Tandem Suspension Effects
10. Kingpin Forces

D. OUTPUT

1. Deceleration
2. Nominal Line Pressure and Individual Brake Pressures
3. Brake Factors
4. Brake Effort: % Front, % Rear, % Trailer
5. Required Friction Coefficient for Each Axle
6. Braking Efficiency, Each Axle
7. Kingpin and Suspension Forces
8. Total Brake Force
9. Brake Force Each Axle

TABLE E-1 (Concluded)

BRAKE PERFORMANCE DIAGRAM CALCULATION
PROGRAM FOR 3-S2 TRACTOR-TRAILER

10. Axle Loads
11. Average Deceleration
12. Stopping Distance

E. INCREMENT LINE PRESSURE

If $p_o < 100$ psi, Go Back to 3, Otherwise Stop

TABLE E-2

DIGITAL COMPUTER PROGRAM TYPICAL INPUT/OUTPUT

Input Data

VEHICLE GEOMETRY

ψ_1 = static tractor rear axle load divided by tractor weight = 0.495

ψ_2 = static trailer axle load divided by trailer weight = 0.51

x_1 = weight of center of gravity of tractor mass divided by tractor wheel base L_1 = 0.22

x_2 = weight of center of gravity of trailer mass divided by kingpin to trailer axle distance L_2 = 0.155

z_1 = height of kingpin divided by tractor wheel base = 0.293

z_2 = height of kingpin divided by kingpin to trailer axle distance L_2 = 0.12

W_1 = tractor weight = 11,580 lb

W_2 = sprung trailer weight = 58,760 lb

y = kingpin to tractor rear axle distance divided by tractor wheel base L_1 = 0.85

L_1 = tractor wheel base = 162 in.

L_2 = kingpin to trailer axle distance = 391 in.

SUSPENSION GEOMETRY

Leaf springs with equalizer (trailer)

Leaf spring length b = 34 in.

Equalizer lever arm c = 7.0 in.

Equalizer lever arm d = 7.0 in.

TABLE E-2 (Continued)

DIGITAL COMPUTER PROGRAM TYPICAL INPUT/OUTPUT

Height of spring attachment $v = 16.8$ in.

Height of center of gravity of axle mass $u = 21.0$ in.

Weight of forward axle $W_{F2} = 1500$ lb

Weight of rearward axle $W_{R2} = 1500$ lb

Walking beam suspension (tractor)

Height of suspension attachment $v_1 = 19.6$ in.

Height of center of gravity of axle mass $u_1 = 20.0$ in.

Pivot to forward axle distance $S = 25.0$

Axle to axle distance $q = 50.0$ in.

Weight of forward axle $W_{F1} = 2{,}300$ lb

Weight of rearward axle $W_{R1} = 2{,}300$ lb

BRAKING SYSTEM

Lining fade coefficient = 0.016, lining friction coefficient (high, μ_{Lh} and low, μ_{Ll})

Q = number of brakes per axle

p_o = pushout pressure (psi)

A = brake chamber area (in.^{2})

r = drum radius (in.)

ρ = lever ratio between brake chamber and shoe actuation

c = brake sensitivity determined from theoretical brake factor curve

TABLE E-2 (Continued)

DIGITAL COMPUTER PROGRAM TYPICAL INPUT/OUTPUT

Co = constant determined from theoretical brake factor curve

η = mechanical efficiency accounting for losses between brake chamber and shoe actuation

Front Axle: $Q = 2$, $p_o = 5.0$, $A = 12$, $r = 7.5$, $\rho = 4.76$, $c = 15.0$, $Co = 2.7$, $\eta = 0.88$, $\mu_{Lh} = 0.47$, $\mu_{Ll} = 0.30$

Tractor Tandem Axle:

Forward: $Q = 2$, $p_o = 2.5$, $A = 30.0$, $r = 8.25$, $\rho = 6.5$, $c = 9.2$, $Co = 1.0$, $\eta = 0.70$, $\mu_{Lh} = 0.36$, $\mu_{Ll} = 0.70$

Rearward: $Q = 2$, $p_o = 2.5$, $A = 30$, $r = 8.25$, $\rho = 5.0$, $c = 9.2$, $Co = 1.0$, $\eta = 0.70$, $\mu_{Lh} = 0.36$, $\mu_{Ll} = 0.20$

Trailer Axle:

Forward: $Q = 2$, $p_o = 2.5$, $A = 30$, $r = 8.25$, $\rho = 5.0$, $c = 5.5$, $Co = 0.0$, $\eta = 0.7$, $\mu_{Lh} = 0.35$, $\mu_{Ll} = 0.20$

Rearward: $Q = 2$, $p_o = 2.5$, $A = 30$, $r = 8.25$, $\rho = 6.0$, $c = 5.5$, $Co = 0.0$, $\eta = 0.70$, $\mu_{Lh} = 0.35$, $\mu_{Ll} = 0.20$

Application time $t_a = 0.05$ sec

Buildup time to reach 100 psi line pressure $t_b = 1.0$ sec

Initial velocity $v_i = 60$ mph

Tire/road friction coefficient $\mu_{road} = 0.70$

Output Data

AT 42.5 psi

Deceleration: 0.375 g

Line pressure 42.5 psi

Axle line pressure front to rear (psi) 37.5, 40, 40, 40, 40

TABLE E-2 (Concluded)

DIGITAL COMPUTER PROGRAM TYPICAL INPUT/OUTPUT

Brake factor = total drum drag divided by actuating force of one shoe front to rear 3.553, 1.616, 1.616, 1.535, 1.535

Required tire/road friction coefficient to prevent wheel lock up front to rear 0.381, 0.295, 0.530, 0.561, 0.302

Braking efficiency = deceleration in g units divided by required friction coefficient front to rear 0.983, (1.268), 0.706, 0.668, (1.239)

Brake force distribution front to rear 0.169, 0.435, 0.395

Individual brake force front to rear (lb) 4,961, 7,190, 5,530, 5,253, 6,303

Individual axle loads front to rear (lb) 13,010, 24,313, 10,422, 9,360, 20,832

INTERNAL PARAMETERS

G, H, Y_2, kingpin force Y = 31,566.984 lb normalized horizontal and vertical kingpin force FKXN = 0.188, FKYN = 0.511, i.e., Y = 0.511 x $(W_2 + W_{F2} + W_{R2})$ = 31,566 lb

Total brake force F_{Total} = 29,239 lb

Average deceleration a_{xm} = 10.49 ft/sec^2

Stopping distance = 370.5 ft

Appendix F

FORMULATION OF MEASURES OF EXPECTED BRAKE PERFORMANCE

Three design measures were employed to assess expected vehicle brake performance based upon vehicle and brake system design data available from vehicle manufacturers. These measures indicate the capability of the braking system to convert mechanical energy into thermal energy (q_L), act as a dissipation element for thermal energy (q_D), and provide wear resistance (μP_M).

F.1 CONVERSION OF MECHANICAL ENERGY INTO THERMAL ENERGY

The measure q_L gives the horsepower generated by the brake per unit area of the lining in units of hp/ft^2. The average kinetic energy transferred into thermal energy at the friction surface during the braking process is:

$$(q)_{av} = \frac{W(V_1 + V_2)\cdot a}{2 \times 778} \left(\frac{btu}{sec}\right) \qquad \text{(F-1)}$$

where
- W = vehicle weight (lb)
- V_1 = initial vehicle velocity
- V_2 = final vehicle velocity
- a = deceleration in g-units

In terms of hp:

$$(hp)_{av} = \frac{W(V_1 + V_2)\cdot a}{1100} \,(hp) \qquad \text{(F-2)}$$

The horsepower into the lining is:

$$q_L = \frac{(hp)_{av}\cdot \phi_i/2\cdot\lambda}{A_L} \qquad \text{(F-3)}$$

where
- A_L = lining area of leading or secondary shoe
- ϕ_i = braking effort at a given axle divided by the total braking effort of the vehicle
- λ = fraction of braking effort contributed by leading or secondary brake shoe*

*Strien (169) finds that $\lambda = 0.5$ for two leading shoe brake and 0.7 for leading-trailing and duo-servo brake.

F.2 DISSIPATION OF THERMAL ENERGY

The measure q_D gives the heat flux into the drum in Btu/ft^2 - sec.

$$q_D = \frac{(q)_{av} \cdot \phi_i/2}{A_D} \qquad (F\text{-}4)$$

where A_D = diam x π x width = swept area of drum

F.3 WEAR MEASURE

The wear measure is calculated from $D = \mu N$

where
D = tangential drag force on one shoe
μ = lining friction coefficient
N = normal force between shoe and drum

$$D = \lambda \cdot W \cdot a \cdot \frac{\phi_i}{2} \cdot \frac{R}{r} \quad \text{and} \quad N = p_m \cdot A_{L_P} \quad \text{where}$$

R = effective tire radius
r = drum radius
A_{L_P} = projected lining area of leading or secondary shoe
p_m = average pressure of shoe against drum

Therefore, the wear measure is given by:

$$\mu p_m = \lambda \cdot W \cdot a \cdot \phi_i/2 \cdot R/r \cdot \frac{1}{A_{L_P}} \qquad (F\text{-}5)$$

F.4 SAMPLE CALCULATIONS

Sample calculations are given below for two of the vehicles tested in the program.

1. International Harvester CO 4070 A
   Max. GVW 39,000 lb
   Front brakes 15 x 4 (data book) (wedge)
   15 x 3 1/2 (as tested) wedge
   Rear brakes 15 x 7 (wedge)

Employing Equations 4-2, 4-4, and 4-11 and brake system design data for this vehicle, the brake distribution is given by

$$\phi_{Tractor} = \frac{5.63 \times 4.4}{5.63 \times 4.4 + 4.06 \times 2.0} = 0.754 \qquad \text{(F-6)}$$

i.e., the rear axle braking effort is 75.4 percent of the total. The average energy is ($V_2 = 0$)

$$(q)_{av} = \frac{39,000 \times 103 \times 0.65}{2 \times 778} = 1680 \frac{Btu}{sec} \qquad \text{(F-1)}$$

$$(hp)_{av} = (q)_{av} \times 1.41 = 2370 \text{ hp}$$

$$q_D = \frac{1680 \times 0.754/2}{15 \times \pi \times 7/144} = 276 \frac{Btu/sec}{ft^2} \qquad \text{(F-4)}$$

$$q_L = \frac{2370 \times 0.754/2 \times 0.5}{2.29 \times \frac{240}{360} \times 0.5} = 585 \frac{hp}{ft^2} \qquad \text{(F-3)}$$

$$\mu \times p_m = 0.5 \times 39,000 \times 0.65 \times \frac{0.754}{2} \times \frac{22.3}{7.5} \frac{1}{15 \times 7 \times 0.9}$$

$$= 150 \text{ psi} \qquad \text{(F-5)}$$

2. Ford F-7000
   Max. GVW 25,500 lb
   Front brakes: 16 x 2 1/2 (S-cam)
   Rear brakes: 16 1/2 x 6 (S-cam)

Employing Equations 4-2, 4-3, and 4-11 and brake system design data for this vehicle, the brake force distribution is given by

$$\phi_{Tractor} = \frac{24.0 \times 6 \times 2.2}{24 \times 6 \times 2.2 + 9 \times 5 \times 1.8} = 0.796 \qquad \text{(F-7)}$$

i.e., the rear axle braking effort is 79.6 percent of the total. The average energy is ($V_2 = 0$)

$$(q)_{av} = \frac{25{,}500 \times 103 \times 0.65}{2 \times 778} = 1100 \ \frac{\text{Btu}}{\text{sec}} \qquad \text{(F-1)}$$

$$(hp)_{av} = 1550 \ \text{hp}$$

$$q_D = \frac{1100 \times 0.796/2}{16.5 \times \pi \times 6/144} = 203 \ \frac{\text{Btu/sec}}{\text{ft}^2} \qquad \text{(F-4)}$$

$$q_L = \frac{1550 \times 0.796/2 \times 0.7}{2.16 \times \frac{240}{360} \times 0.5} = 600 \ \frac{\text{hp}}{\text{ft}^2} \qquad \text{(F-3)}$$

$$\mu \times p_m = 0.7 \times 25{,}500 \times 0.65 \times \frac{0.796}{2} \times \frac{19.8}{8.25} \ \frac{1}{16.5 \times 6 \times 0.9}$$

$$= 124 \ \text{psi} \qquad \text{(F-5)}$$

Appendix G

TRAILER BRAKE SYNCHRONIZATION DEVICE

The purpose of the trailer brake synchronization device—the Syncron System*—is to decrease the application and release times of the trailer brakes on a combination vehicle.

This system (shown schematically in Fig. G-1) consists of all basic normal brake system components plus electromagnetic air valves, an impulse valve, supplementary air tanks, an electrical delay relay, a two-way check valve and pressure regulator. Physically, a tap of the trailer reservoir is made and brought through a pressure regulator to a small reserve tank, and then through the electromagnetic air valve. The electromagnetic air valve supplies pressure to the relay emergency service port. A two-way check valve is inserted for flow control and protection of the standard system. All of this piping is as short as possible to reduce transmission time to the relay emergency valve. The electrical delay relay is positioned where convenient near the installation with connections into a mechanically actuated switch on the brake pedal and output to the electromagnetic valve.**

The system operates as follows:

Actuation of the mechanical switch on the brake pedal applies voltage to the delay timing circuit (solid state component) which applies voltage to the electromagnetic valve opening the auxiliary air circuit. Air is then supplied by the small reserve tank off the pressure regulator valve to the service air circuit of the relay emergency valve for a predetermined length of time (timer setting). The relay valve in turn admits air to the brake chambers. Backflow into the service line is prevented by a two-way check valve. The timer and regulator were set on the system used on Vehicle 12 to give an impulse of 35 psi magnitude for a duration of 0.150 sec.

The service brake chambers will begin to fill but never reach more than a few psi before the timer deenergizes the air circuit. Meanwhile, normal service air signal pressure has risen in the service line or is rising and now takes over the command of service line pressure at the relay emergency valve. The system now reverts to standard operation.

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*Trade name of the system supplied for this program by the Berg Manufacturing and Sales Company, Des Plaines, Illinois.

**The use of the separate foot-pedal-actuated switch requires separate electrical interface connections between the tractor and the trailer.

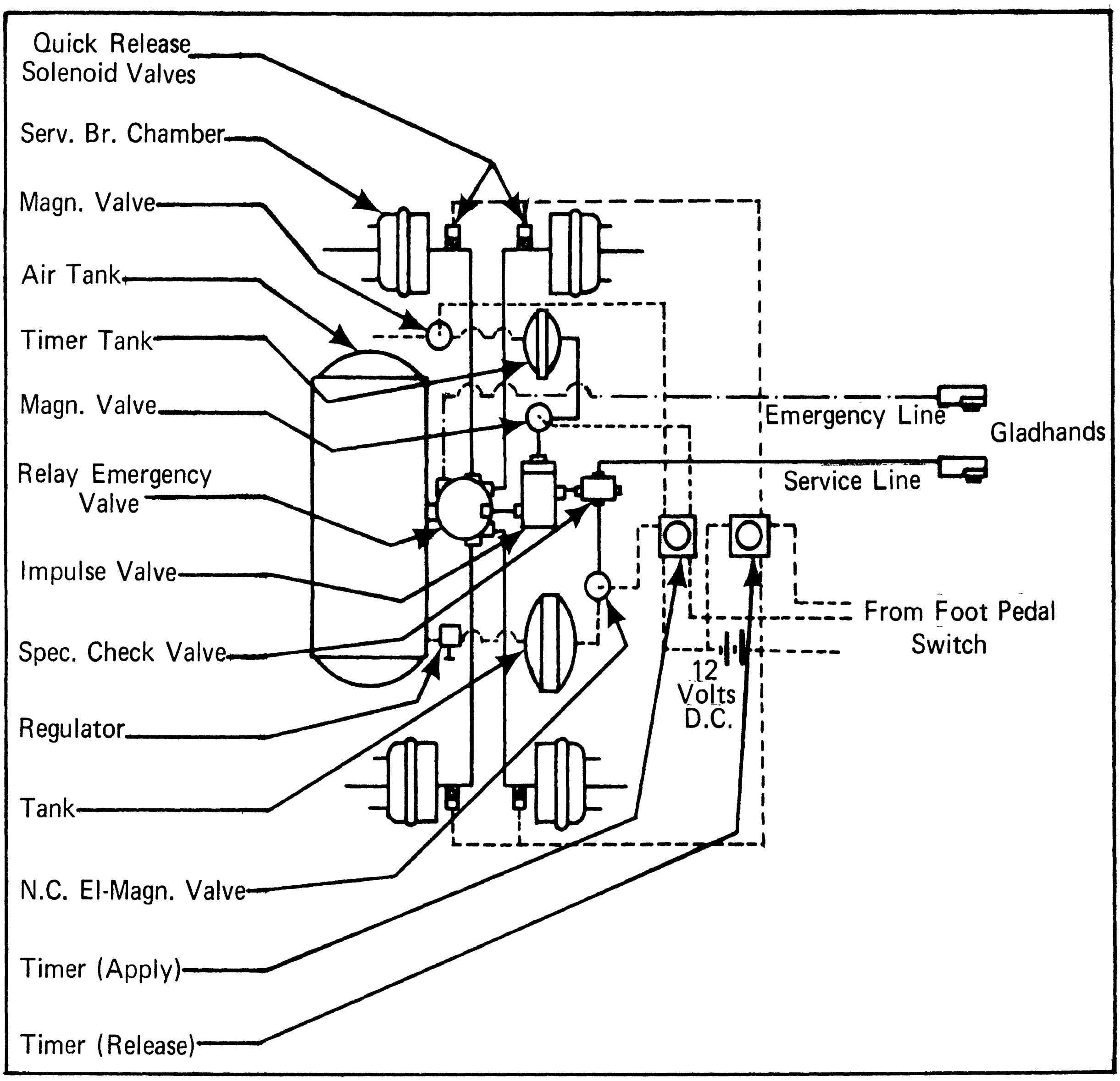

FIGURE G-1. SYNCRON SYSTEM SCHEMATIC

The impulse system dramatically improves response times for brake application, but has no effect on brake release. Improvement in brake release time is accomplished by the incorporation of electrically controlled solenoid valves to exhaust trailer brake chamber pressure at each brake chamber. Actuation of these valves causes the maximum rate of decay of pressure in the brake chamber. Referring again to Fig. G-1, release of the brake pedal switches on the second circuit incorporating a time delay relay which in turn actuates the solenoid valves at the brake chambers, exhausting air directly to atmosphere and closing off the supply to the chambers. Upon completion of the delay cycle, the solenoid valves are deactuated, reverting to standard configuration and thereby failsafe in operation.

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