AD-A170 798 FEASIBILITY OF ROUGH TERRAIN FORKLIFT TRUCKS WITH A ROAD SPEED CAPABILITY OF 45 MPH(U) LITTLE (ARTHUR D) INC CAMBRIDGE MA J S HOWLAND MAY 86 ADL-54964 1/3

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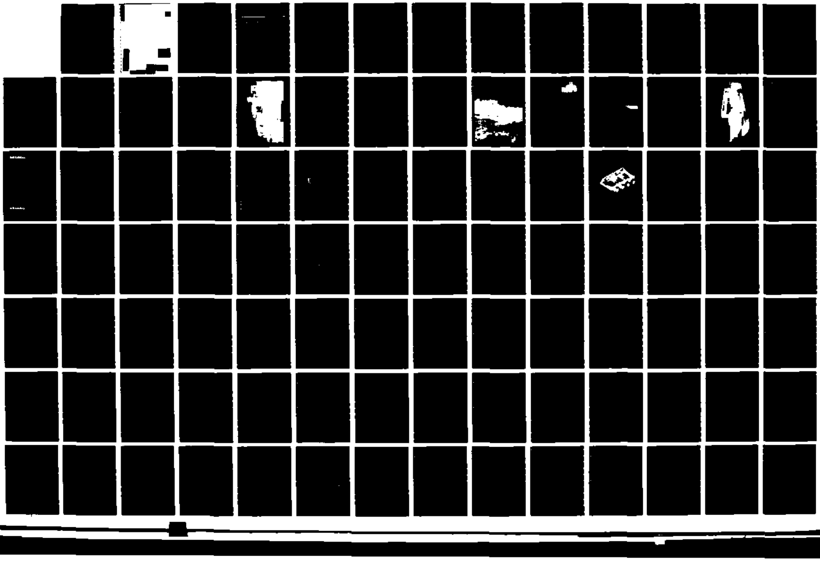

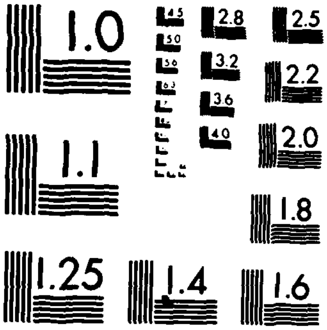
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ADA 170 798

Final Technical Report to

U.S. Army Belvoir Research
and Development Center
Fort Belvoir, VA
May 1986

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Feasibility of Rough Terrain Forklift Trucks with a Road Speed Capability of 45 mph

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1. INTRODUCTION

1.1 BACKGROUND

Military Rough Terrain Forklift Trucks (RTFLT) are currently adapted from commercial construction vehicle designs. Like their commercial cousins, they are limited to maximum road speeds in the range of 20 mph.

In order to deploy RTFLT's to work locations in the field, they must be transported on a flatbed trailer or towed by another vehicle. In today's modern, highly mobile Army, areas of operations can change rapidly and frequently. The need to maintain suitable towing or trailering vehicles with each RTFLT imposes a significant logistical burden on the operation. In the worst case, the equipment would not be available and delays would occur until the forklifts could catch up with the fighting units.

Thus, there is a need to examine feasibility of increasing the speed of RTFLT's over the road so that they can be self-deployable. Speeds of 45 mph over the road or on improved surfaces would achieve this goal.

1.2 OBJECTIVE

The objectives of this study have been threefold:

- The identification of each technical obstacle to the operation of current Army RTFLT's at 45 mph over improved surfaces;

- The definition of system and component modifications that would be required to achieve this performance; and

- The determination of commercial availability for modified components.

1.2 METHOD OF APPROACH

The general method of approach consisted of three phases aimed at the above three objectives. In Phase I, Problem Identification, a literature review was conducted and the current vehicle manufacturers were consulted to determine the state of the art and any available background information. The critical areas were identified and an analytical approach selected, where needed, to quantify the limitation in performance and modifications in performance required to increase the speed.

In Phase II, Component Performance, those systems requiring modification and capable of being analyzed within the scope of the study to set required component performance levels were subjected to more detailed analysis. In some cases, detailed analysis to set required level of performance was not necessary and commercial availability could be readily assessed from the basic speed requirements. In others, such as steering, an extremely complex system analysis would be required, based on detailed vehicle and component design data not available without experimental development. Here, the analysis was used to assess the overall system to determine whether any critical areas exist where component availability is likely to preclude the desired performance.

Finally, in Phase III, Component Availability, the critical components which can be specified without vehicle testing at high speeds are assessed for commercial availability.

In Chapter 2, the major tasks and principal results and conclusions are summarized.

2. SUMMARY

Phase I of this study included discussions with vehicle and component manufacturers, literature search and review, analysis of the vertical and pitch dynamics of the current vehicles, and analysis of lateral dynamics and handling characteristics. On the basis of these studies, it was concluded that the potential problem areas impeding the operation of current Army RTFLT's at 45 mph are as follows:

- Violent vertical and pitch oscillations will occur for road excitation frequencies near the natural frequencies of the vehicle. This excitation will be the expected normal condition for high-speed operation.
- Potential handling instabilities and resulting difficulty in directional control.
- Difficulty in assembling a suitable drivetrain made up of available components which will provide both low-speed gradeability and high-speed operation.
- Difficulty in obtaining suitable off-road tires which can also be operated for reasonable periods at 45 mph.

In Phase II, the first three of these problem areas were analyzed from the standpoint of determining the required component performance to overcome the potential problems. The results of these studies were as follows:

- A compliant suspension system is needed between the axles and the frame of the vehicles for operation at 45 mph.
- The most flexible type of suspension system for adaptation to existing vehicles appears to be the hydropneumatic system which has been used successfully on a number of similar vehicles in the past.

- Dynamic analysis of the existing Army RTFLT's with a suspension system added shows that acceptable vertical and pitch dynamics can be obtained with reasonable hydraulic components. These types of components are readily available in a range of sizes and configurations.

- Lateral dynamics and handling characteristics cannot be analyzed accurately enough with available data to confirm that the performance is limiting or to design steering systems and select components. In fact, the analysis suggests that handling will be more affected by the general vehicle design and weight distribution than by the components selected for the steering system. The latter are readily available in a variety of sizes and configurations for this type of vehicle. It is believed that 45 mph handling characteristics can only be determined by testing of a high-speed test vehicle.

- Tires, being simply a question of available components, were deferred to Phase III for consideration.

In Phase III, the major questions of available components that can be addressed without a detailed experimental development program were studied. These are tires and driveline components. The major findings are:

- Tires in equivalent sizes are available for the 4K and 6K machines for which there is some available data on high speed capabilities. However, it is possible that some limitation may be placed by the heat buildup on the distance or period of time allowable at 45 mph.

- Variable inflation pressures may be used to extend the speed capabilities of this type of tire.

- For the 10K machine, it is not clear from available information whether there is an available tire which can provide the desired rough terrain capabilities as well as 45 mph for reasonable periods of time.

- Testing of the optimum available tires will be required for heat buildup at the required loads and speeds. This is usually done on a tire testing machine.

- Significant driveline modifications are required on all three vehicles to achieve 45 mph operation. Wider range powershift transmissions are required and lock-up torque converters are needed for high speed operation. The overall axle ratio must be reduced for the 6K and 10K machines. Significantly higher power engines are required on all three machines.

- There does not, however, appear to be any limitation imposed on the implementation of the upgraded drivelines by lack of available components. A careful detailed design process is required to select the optimum components and to modify the vehicle to fit these components in and mount them.

The next step in the development program should consist primarily of experimental evaluation of one or more RTFLT machines. For this, a high speed vehicle test bed is required. This can be either

- an upgraded existing similar machine with a suspension system such as the Zettelmeyer ZC75C, or

- a modified M4K and/or M10A with an added suspension system and upgraded drive components to meet, at least, the high-speed 0specifications. The M10A size is expected to present the most serious handling limitations at high speed.

This test vehicle should be tested to investigate the handling characteristics and to optimize the suspension system design.

It should be noted that the primary purpose of this test program is the investigation and development of high speed vertical dynamics and handling characteristics or lateral dynamics. Thus, the capability of the test bed at 45 mph is of primary importance. In a prototype vehicle design, of course, which could be deferred to a later development phase, low speed gradeability would also be necessary.

In a parallel test program, tire testing for heat buildup should be conducted on tires selected in consultation with the major tire manufacturers.

3. DESCRIPTION OF EXISTING VEHICLES

3.1 CURRENT ARMY ROUGH TERRAIN FORKLIFT TRUCKS

This study is aimed at evaluating the feasibility of extending the specifications covering current Army RTFLTs to 45 mph. In the following subsections, the major specifications for the three Army machines of interest are summarized. The production vehicles which currently implement two of these specifications, are described in detail along with a prototype version of the third.

3.1.1 4000-Pound RTFLT

The 4000 lb. RTFLT is designed to meet Military Specification, MIL-T-52941, dated 29 November 1977. (1)* The principal requirements are summarized in Table 1.

This specification is implemented by the J. I. Case M4K vehicle which is an articulated steering machine. The M4K is shown unstuffing a MILVAN container in Figure 1. The major specifications for the M4K are tabulated in Table 2.

The M4K was derived from an earlier MC4000 supplied to the Marine Corps. The MC4000 had a top speed of 35 mph. A number of units were also supplied to the Israeli Army with higher engine speed, allowing a 45 mph top speed. At 35 mph, the MC4000 reportedly ran well on the beach and on paved roads. However, on dirt roads, they reportedly exhibit considerable heave and porpoising (pitch) oscillations. The 45 mph units were reportedly very difficult to control.

---

*Numbers in parentheses refer to the list of references in the Bibliography.

TABLE 1

PRINCIPAL REQUIREMENTS FOR THE 4000 lb. RTFLT

Rated Load:	4000 lb. at 24-inch load center
Weight:	11,000 lb. or less
Height:	80 inches or less
Length:	166 inches or less
Width:	79 inches or less
Underclearance:	10 inches or greater
Stability:	Full circle on a 30% slope with full load
Gradeability:	45% slope with rated load at 2 mph or greater
Fording Depth:	20 inches or greater
Curb Clearance:	39 foot diameter or less
Travel Speed:	20 mph or greater - forward 10 mph or greater - reverse
Type of Steering:	Articulated, or Ackerman (Ackerman to provide two wheel rear or four-wheel cramp steering)
Type of Forklift:	Mast type

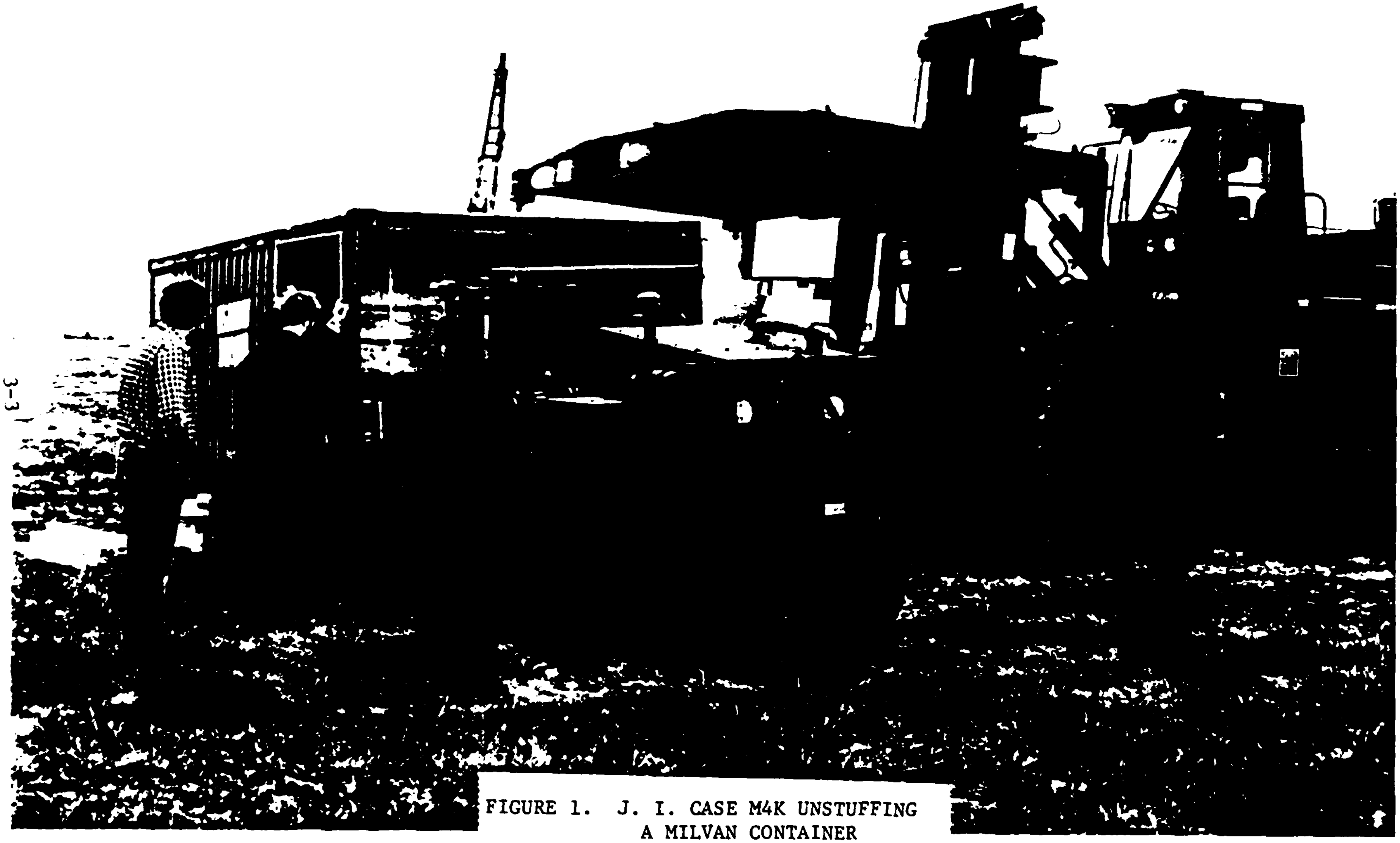


FIGURE 1. J. I. CASE M4K UNSTUFFING A MILVAN CONTAINER

TABLE 2

MAJOR SPECIFICATIONS - J. I. CASE M4K

Model	**M4K**	**M4K**
Operating Data	**Metric**	**English**
Type of Lift	Mast	Mast
Lift Capacity Rated	1814 kg @ 610 mm	4000 lbs. @ 24"
Maximum Lift Height	2 54 m	100"
Degrees of Tilt - Forward *Rearward*	11° 22°	11° 22°
Sideshift	559 mm Left, 559 mm Right	22" Left, 22" Right
Fork Rotation Angle	20° Total	20° Total
Dimensions and Weight		
Length - Overall	5 21 m	205"
Maximum Height to top of ROPS or Cab	2 03 m	80"
Ground Clearance @ center of wheelbase	343 mm	13 5"
Wheelbase	2 34 m	92"
Width over tires	2 01 m	79"
Turning Radius (outside of tires)	4 06 m	13'4"
Turning Angle (left and right)	43°	43°
Weight - No load - less operator Front axle - no load Rear axle - no load	4411 kg 2125 kg 2286 kg	9725 lbs 4685 lbs 5040 lbs
Weight - With rated load Front axle - loaded Rear axle - loaded	6226 kg 4903 kg 1322 kg	13,725 lbs 10,810 lbs 2915 lbs
Engine - Make and Model - Diesel	Case - G207D	Case - G207D
Horsepower (SAE Net @ RPM)	41 0 kW @ 2200 RPM	55 H P
Transmission - Make and Model	Clark - 11 2 HR 18340	Clark - 11 2HR 18340
Type - Number Speeds F R	Full Powershift 3F 3R	Full Powershift 3F 3R
Type - 1st - empty 2nd 3rd 4th	5 3 km hr - F&R 11 6 km hr - F&R 32 5 km hr - F&R –	3 3 mph - F&R 7 2 mph - F&R 20 2 mph - F&R –
Axles - Make	Rockwell	Rockwell
Tire - Size	15 x 19 5 - 8PR	15 x 19.5 - 8PR
Electrical System - Voltage	24 volt	24 volt
Capacities		
Fuel Tank	102L	27 Gal.
Cooling	17L	4 5 Gal
Hydraulic System	61 5L	65 Qts.
Transmission, Torque Converter	20 8L	22 Qts.
Engine Crankcase	6.6L	7 Qts.
Axles (Each)	15 2L	16 Qts.
Other Special Features	Helicopter Transportable Container Compatible Towable - Single Lever Axle Disconnect Driving - Flood and Blackout Lighting ROPS FOPS Canopy (Removable) Hydraulic Sideshift Hydraulic Fork Rotation Lift and Tiedown Provisions 50" Free Lift	

3.1.2 10,000-Pound RTFLT

The 10,000 lb. RTFLT is designed to meet Military Specification, MIL-T-52843C, dated 1 May 1985. (2) The principal requirements are summarized in Table 3.

The earlier "B" version of this specification was implemented by the International-Hough M10A vehicle. This vehicle is a modified bucket loader as shown in the photograph of Figure 2. The major specifications for the M10A are summarized in Table 4.

The M10A, or similar vehicles, have never been tested by International-Hough at speeds above 22 mph. At this speed on a smooth asphalt track, the vehicle undergoes heave or porpoising oscillations and tends to oversteer.

3.1.3 6000-Pound Variable Reach RTFLT

The 6000 lb. Variable Reach, Rough Terrain Forklift Truck (VRRTFLT) is covered by Military Specification, MIL-T-53038 (ME), dated 21 March 1984. (3) The principal requirements are summarized in Table 5.

The 6000 lb. VRRTFLT is not yet in production. However, a prototype vehicle was the Gradall 534B, shown in military colors in Figure 3. The major specifications for the Gradall 534B are summarized in Table 6.

The Gradall vehicle incorporates two wheel Ackerman steering on the rear wheels. These are capable of nearly 90° steering angle, allowing the vehicle to pivot about the inside front wheel. This gives an attractive combination of minimum turning circle (about 29 feet) with fairly long wheelbase (135 inches).

TABLE 3

PRINCIPAL REQUIREMENTS FOR THE 10000 LB. RTFLT

Rated Load:	10,000 lb. at 48-inch load center
Weight:	37,000 lbs. or less; reduceable to 33,000 lbs. for air transportability with maximum axle load of 19,000 lbs.
Height:	103 inches or less, with ROPS, muffler, and cab removed if necessary.
Axle Spacing:	108 inches or less
Width:	111 inches or less
Ground Clearance:	13 inches or more (20 degrees or greater angles of approach and departure)
Stability:	full circle on a 25% slope with rated load
Gradeability:	45% slope with rated load at 2 mph or greater
Fording Depth:	60 inches of seawater
Curb Clearance:	45 foot diameter or less
Travel Speed:	20 mph or greater - forward, unloaded 15 mph or greater - forward, loaded 7.5 mph or greater - reverse, loaded
Type of Steering:	Articulated
Type of Forklift:	Arm type

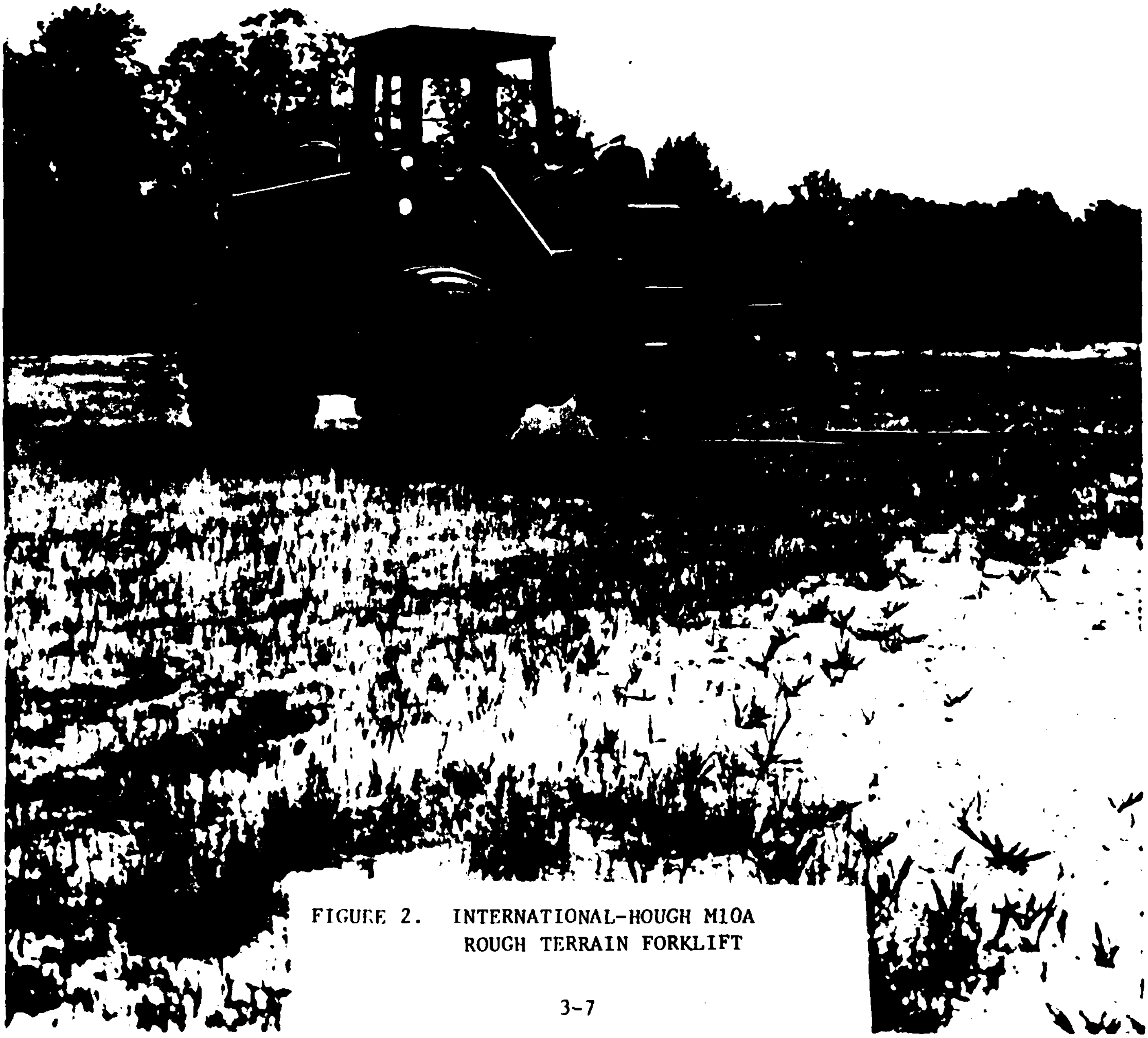
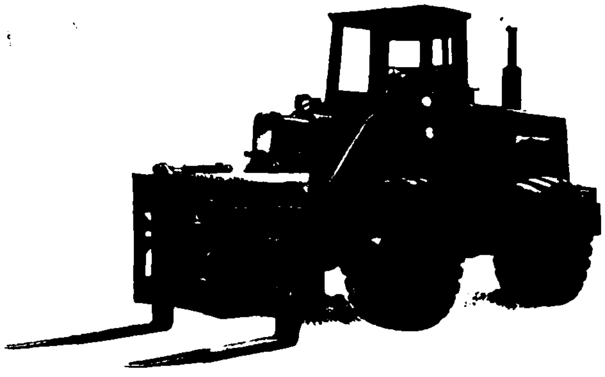


FIGURE 2. INTERNATIONAL-HOUGH M10A ROUGH TERRAIN FORKLIFT

TABLE 4

MAJOR SPECIFICATIONS - INTERNATIONAL-HOUGH M10A

M10A Rough [illegible] Forklift



- **10 000 lb (4536 kg) capacity at 48" (1219 mm) load center to a height of 120"**
- **All-around disc brakes**
- **4-wheel drive**
- **Hydraulic fork spreading, side shifting and oscillation capabilities**
- **Water fordable to 60" (1.52 m)**

ENGINE

Make and Model	International DT-466B
Type	4 cycle diesel, turbocharged, direct start, direct injection
*Rated hp (kW)	200 (149)
**Flywheel hp (kW)	184 (137)
governed rpm	2500
Max. torque @ 1800 rpm lb ft (N·m)	492 (363)
Bore and Stroke, in (mm)	4.3 x 5.35 (109 x 136)
No. of cylinders	6
Displacement, in³ (L)	466 (7.63)
Electrical system	24 Volt
AMA HP U.S. tax purposes	44.4

**Rated power output of standard engine complete with water pump, lubricating oil pump and fuel pump under SAE standard ambient temperature and barometric conditions of 29. 38" Hg and 85°F (99.2 kPa and 29.4°C).*

**Flywheel power output of standard engine as installed in this vehicle with addition of fan, air cleaner, alternator, and air compressor.

TORQUE CONVERTER

Single stage, single phase type, 1.963 to 1 stall ratio.

TRANSMISSION

Full power shift, countershaft type, constant mesh.

Speeds	**1st**	**2nd**	**3rd**
Forward, mph (km/h)	4.7 (7.6)	9.5 (15.3)	22.0 (35.4)
Reverse, mph (km/h)	5.7 (9.2)	11.4 (18.3)	22.0 (35.4)

DIFFERENTIALS

Power transfer.

AXLES

Heavy-duty type with full-floating axle shafts and planetary final drives. Four wheel drive.

Front axle fixed; rear axle oscillates a total of 28°. Vertical wheel travel of 19" (483 mm).

STEERING

Articulation right or left .... 29°

Full hydraulic power – smooth steering at any engine speed.

BRAKES

Service – Four wheel air-over-hydraulic, dry disc, caliper brakes with separate axle-by-axle operation. Operator's choice braking: left pedal neutralizes transmission and applies brakes, right pedal applies brakes only.

Parking – drum type, air release, spring apply.

LOADER LINKAGE

Sealed pivot points and Z-bar with extended lubrication intervals.

FULLY HYDRAULIC FORK LIFT FUNCTIONS

Type: Closed with pressure control 30 psi (0.21 MPa) and vacuum relief.

Raise boom in 12.0 sec. Lower boom in 9.0 sec.

Dump fork in 3.5 sec. Rollback fork in 3.0 sec.

Reservoir: Sight gauge and one 5 micron spin-on type filter. Full flow filtration.

Pump: Single element gear type hydraulic pump.

Main Hyd.: Output at 2500 rpm 28 gal/min at 1000 psi (106 L/min at 6.9 MPa).

Steering Hyd.: Output at 2500 rpm 17 gal/min at 1000 psi (64 L/min at 6.9 MPa).

BOOM FUNCTION

Hydraulically actuated to a lift height of 120 inches (from ground level to top surface of fork tines with tines horizontal) and to a depth of 6 inches below ground level.

TILT FUNCTION

Hydraulically actuated

Rollback @ ground level	13 Degrees
Rollback @ carry position*	22 Degrees
Rollback @ maximum height	56 Degrees
Forward tilt @ carry position	13 Degrees

*Carry position-measured from heel of forks to the ground with forks at full rollback 24" (.61 m).

SIDE SHIFT FUNCTION

Hydraulically powered – 12" (.30 m) (right or left of center).

HYDRAULIC OSCILLATION FUNCTION

Hydraulically actuated – 6 Degrees clockwise and counter clockwise relative to the horizontal center line of the vehicle.

HYDRAULIC FORK SPREAD FUNCTION

Hydraulically actuated – providing the following fork spread capability.

Fork spread min. (measured inside to inside)	4" (.10 m)
Fork spread max. (measured outside to outside)	79" (2.0 m)

SERVICE CAPACITIES (Approx.)

	US gal	(Litre)
Cooling system	15	(56.8)
Lube systems:		
Crankcase	5.5	(21)
Transmission	5	(19)
Differential & final drive, front	8	(30)
Differential & final drive, rear	8	(30)
Hydraulic reservoir	31	(117)
Fuel tank	60	(227)

INSTRUMENTATION

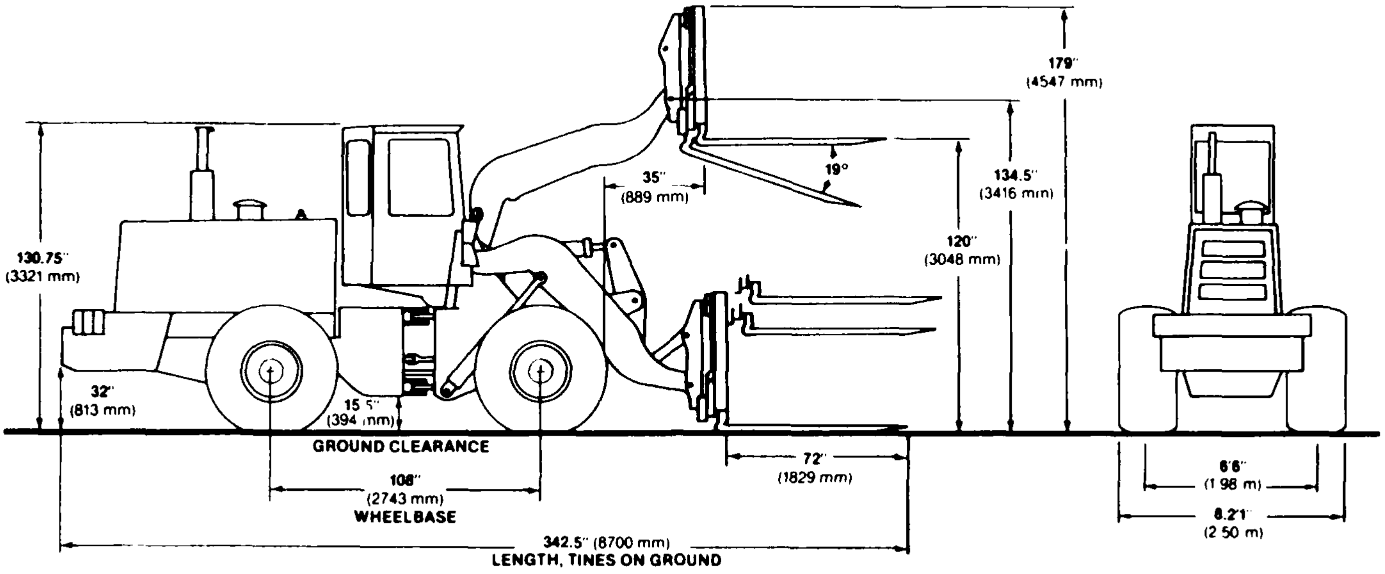
Gauges: Air pressure, Engine coolant temp., Fuel level, Hydraulic reservoir level, Radiator level, Hourmeter, Torque converter oil temp., Voltmeter, Engine oil meter.

Warning lights: *Brake, Parking, Applied, *Brake, Partial system failure warning, Converter temp. overheat, Engine coolant overheat, Engine oil low pressure, Filter change indicator, Hydraulic, and Back up alarm.

*Buzzer, intermittent with warning lights for low air pressure.

TABLE 4 (Continued)

MAJOR SPECIFICATIONS - INTERNATIONAL-HOUGH M10A



ABOVE DIMENSIONS WITH STANDARD 20.5 x 25, 16 PR (L-2 TIRES)

M10A Fork Lift Information		
Capacity @ 48" (1219 mm) load center, lb (kg)		10 000 (4536)
Length of Tines, in (mm)		72 (1829)
Tine Section @ Middle of Tine, in (mm)	Height	2.5 (64)
	Width	8 (203)
Tine Spacing (center to center), in (mm)	Min. inside	4 (102)
	Max. outside	79 (2007)
Maximum Reach, in (mm)		57 (1448)
Reach @ 42" (1067 mm), in (mm)		55.5 (1410)
Curb Clearance Circle per SAE J695, ft (m)		43 (13.1)
Reach @ Max. Lift, Tines Level, in (mm)		35 (889)
Max. Tine Height with Tines Level, in (mm)		120 (3048)
Hinge Pin Height @ Max. Lift, in (mm)		134.5 (3416)
Max. Dump Angle @ Max. Lift		19°
Static Tipping Load, lb (kg)	Straight Ahead	18 730 (8503)
	Full Turn	15 920 (7228)
Operating Weight, lb (kg)		37 000 (16 783)
Rollback @ 24" (609.6 mm) Carry Position		22°
Turning Radius @ 24" (609.6 mm) Carry, Fork Rolled Back, Max. Spread, ft (mm)		24 (8305)

STANDARD EQUIPMENT

Air cleaner, dry-type, dual stage, exhaust aspirated with safety element and indicator
Alternator, 60 amp
Auxiliary steering, ground driven pump type
Electromagnetic interference suppression
Fan guard
Fenders, all four wheels
Filters, transmission, torque converter, cartridge type
Filters, fuel, engine oil, hydraulic oil, spin on
Fungus and moisture resistance, all electrical circuitry, components and connections are protected
Horn, air
Hourmeter
Lights, front and rear working
Master electrical switch
Rain cap, exhaust
Rear pintle hook
ROPS & FOPS Cab (ROPS-SAE J1040) & (FOPS-SAE J231) w/seat belt (SAE J386), heater and defroster.
Safety lock for hydraulic and transmission controls
Seat, adjustable bucket
Tie downs and lifting eyes

TABLE 5

PRINCIPAL REQUIREMENTS FOR THE 6000 LB. VRRTFLT

Rated Load:	6000 lbs. at 24-inch load center
Weight:	35,000 lbs. or less; (axle weight specified as a function of wheelbase).
Height:	102 inches or less
Axle Spacing:	96 inches or less
Width:	102 inches or less
Ground Clearance:	12 inches or greater
Stability:	full circle on a 30% slope with rated load
Gradeability:	45% slope with rated load at 2 mph or greater
Fording Depth:	30 inches or greater
Curb Clearance:	34.5 foot diameter or less
Travel Speed:	17 mph or greater - forward, unloaded 15 mph or greater - forward, loaded but retracted 7.5 mph or greater - reverse loaded but retracted
Type of Steering:	Ackerman
Type of Forklift:	Variable reach boom (with specific load capacities specified at extended reach and height)

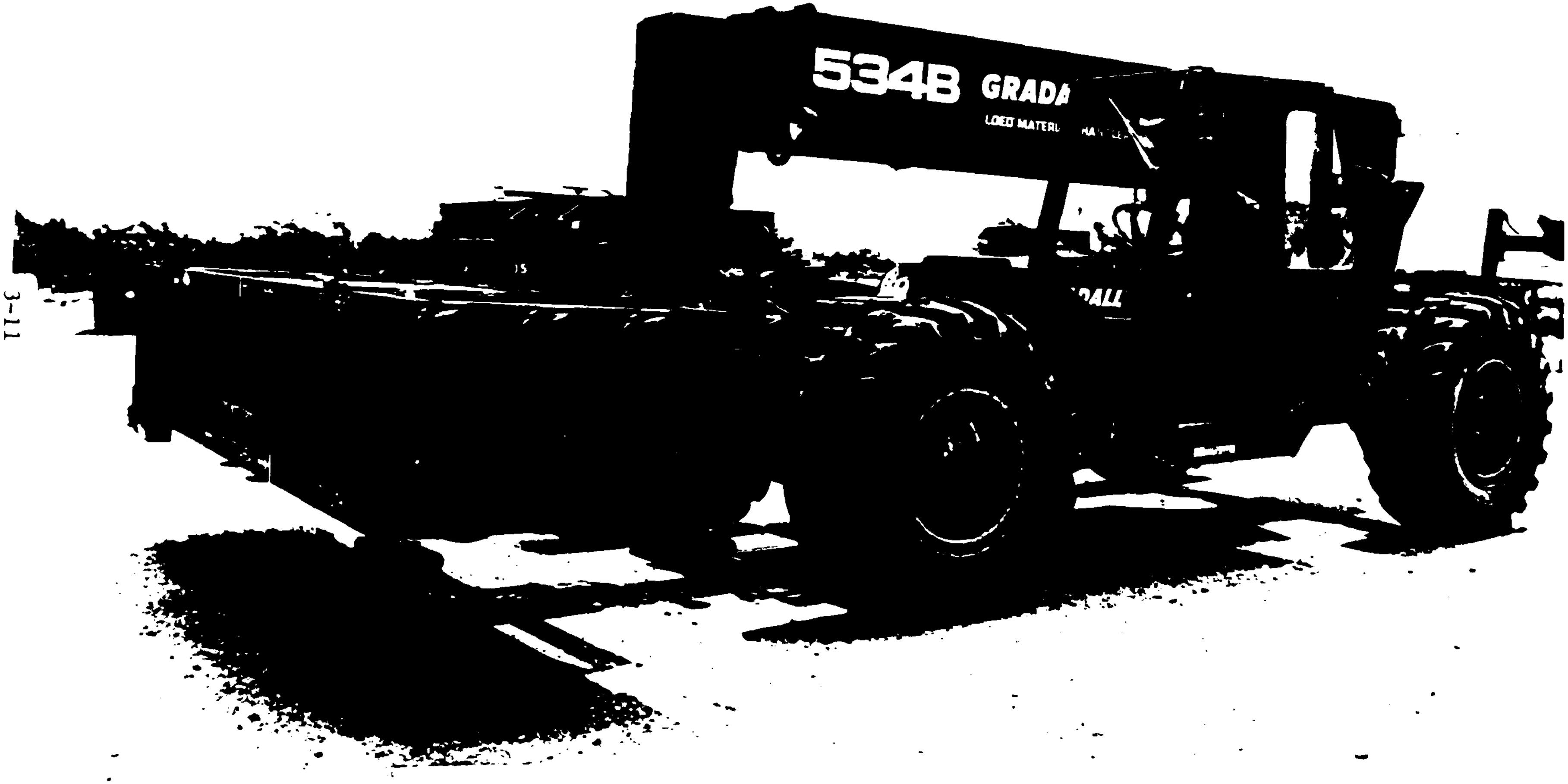


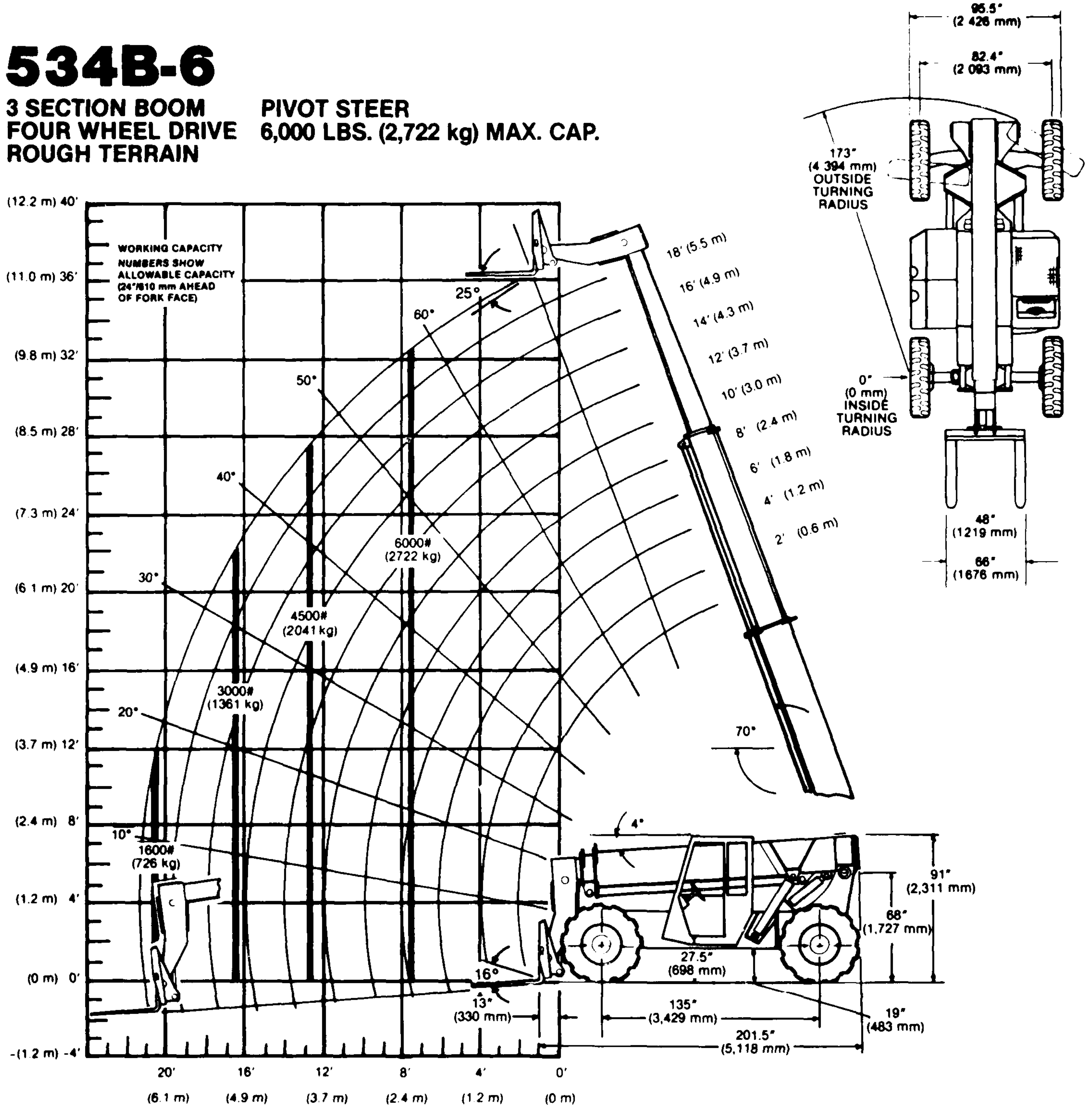
FIGURE 3. GRADALL 534B - 6K VRRTFLT PROTOTYPE

MAJOR SPECIFICATIONS - GRADALL 534B

534B-6

3 SECTION BOOM
FOUR WHEEL DRIVE
ROUGH TERRAIN

PIVOT STEER
6,000 LBS. (2,722 kg) MAX. CAP.



PERFORMANCE SPECIFICATIONS

RATED CAPACITY **at 24" (610 mm) Load Center** . . . . 6,000 lb. (2,722 kg)

LIFT SPEED **(Boom Retracted)**

Empty	129 f.p.m. (39 m/min)
Loaded	103 f.p.m. (31 m/min)

BOOM SPEED

Extend	100 f.p.m. (30 m/min)
Retract	160 f.p.m. (49 m/min)

GRADEABILITY

Empty	65%
Loaded	80%

Limited by traction conditions.

TRAVEL SPEEDS— **Forward & Reverse**

Gear	Speed MPH	(Km/Hr)
1	3.1	(5.0)
2	6.6	(10.6)
3	15.9	(25.6)
Road	17.9	(28.8)

DRAWBAR PULL

Empty	11,000 lb. (4,990 kg)
Loaded	16,000 lb. (7,258 kg)

OPERATING WEIGHT

W/Carriage & Forks . . . . 18,500 lb. (8,390 kg)

IMPORTANT

Rated lift capacities shown are with machine on a firm, level surface with undamaged, properly inflated tires. Machine specifications and stability are based on rated lift capacities at specific boom angles and boom lengths. If specifications are critical, the proposed application should be discussed with your dealer.

DO NOT exceed rated lift capacity loads, as unstable and dangerous machine conditions will result. DO NOT tip the machine forward to determine allowable load.

Handling personnel with the boom is not authorized except with equipment furnished and authorized by Gradall.

GRADALL®

534B MULTI-PURPOSE MATERIAL HANDLER

ACCESSORIES

(ADD-ONS TO THE BASIC UNIT)

CAB ENCLOSURE

All windows and door with Plexiglass.
Lockable, swinging door.
Windshield wiper.

HEATER & DEFROSTER FAN

ROTATING BEACON

AUXILIARY HYDRAULIC CIRCUIT

Required for all attachments equipped with cylinders or other hydraulic components. Consists of valves, controls, hydraulic lines.

This machine is designed to meet specifications of Part II ANSI B56.1-1969 as required by OSHA Section 1910.78(a)(2) and also comply with ANSI B56.1-1975 and B56.6-1978.

It is Gradall Policy to continually improve its products. Therefore designs, materials and specifications are subject to change without notice and without incurring any liability on units already sold.

GRADALL®

New Philadelphia, OH 44663

DRIVE-LINE SPECIFICATIONS:

ENGINE

Make and Model	Perkins T4.236
Fuel..................	Turbo Diesel
Cycles................	4
No. of Cylinders	4
Displacement	235.9 cu. in. (3.9 L)
Rated Speed	2600 rpm
Max. Gross BHP	102 HP (76 kw)
Fuel Tank	40 gal. (151.4 L)

ENGINE FILTERS

Two stage dry air cleaner—centrifugal pre-cleaner with continuous dust ejector PLUS cleanable and replaceable dry filter element.
Replaceable element type fuel filter.
Full flow replaceable element engine oil filter.

ELECTRICAL SYSTEM

Voltage - 12V　Alternator - 61 amp
Battery - 2 @ 565 Cold Cranking AMPs at 0°F. each

TRANSMISSION

Full power shift.　3 speeds forward, 3 speeds reverse.
225 ft. lb. (305 Nm) torque rating.　Neutral start switch.
Shift without stopping.　Inching control.
Transmission speed lever on right on steering column.
Forward, neutral, reverse lever on left on steering column.
Single foot pedal control provides both braking and inching for lifting while maneuvering vehicle.

AXLES

Planetary hubs on rear wheels.
Planetary front axle.

BRAKES

Service — Hydraulic drum on front wheels, hydraulic dynamic breaking on rear wheels.
Parking - Hand set lever sets caliper on drive line disc, Mico brake lock.

TIRES

13:00 x 24 - 12PR, G3 type.
90% CaCl filled on 534B-8.
Optional - 15.5x25 12PR, L2 type on front.

STEERING

Manual steering possible if engine fails.
Rear wheel steering, 90° pivot around either front tire.
Outside turning radius is less than chassis length.

INSTRUMENTS

Ammeter. Back-up alarm (horn). Hour meter.
Engine oil pressure, temperature, fuel gauges.
Converter temperature gauge.

CONTROLS

Grouped for operator comfort and convenience.
Boom lift and crowd lever on right.
Tilt and sway lever on left on dash panel.
Foot throttle on floor.

HYDRAULIC SYSTEM

In-line pump, direct driven from transmission.
Two separate valve sections allow separate or combined operation of boom and tilt functions.
Lift, crowd, tilt, sway cylinders have safety checks to prevent dropping of load in the event of hose or other hydraulic failure.

3.2 EXISTING HIGH-SPEED ROUGH TERRAIN VEHICLES

As discussed in the preceding sections, current Army rough terrain forklift trucks are limited to travel speeds in the 20 mph range. This speed limitation is also typical for all other identified rough terrain forklift trucks.

However, a number of vehicles are available which were developed for other applications and have some potential as platforms for a high-speed forklift truck. These are discussed briefly in the following subsections.

3.2.1 Zettelmeyer ZL 75C

The Zettelmeyer ZL 75C is a wheel loader which can be considered to be a prototype of a high speed, 10,000 lb. forklift machine. It is slightly larger and heavier than the M10A and has a top speed of about 60 Km/hr. or about 37 mph.

The ZL 75C is an articulated machine as shown in Figure 4. Its unique feature is a hydropneumatic suspension system on both axles. This system is load sensitive. The ZL 75C is powered by a 252 hp Deutz diesel. The transmission is a four-speed powershift, and the torque converter incorporates an automatic lockup in 3rd and 4th gear ranges.

The Military Vehicles and Engineering Establishment in the United Kingdom tested the ZD 3000 wheel dozer, which is a very similar machine. (4) The top speed reached in 4th gear was 35.6 mph on dry level asphalt with an approach run.

It would appear that the design approached used for the ZL 75C could be incorporated in a slightly smaller loader converted to forklift operation with sufficient modification to the driveline to produce 45 mph (about 20% speed increase in top gear range).

In any case, the machine provides a valuable empirical baseline for the 45 mph 10K RTFLT.

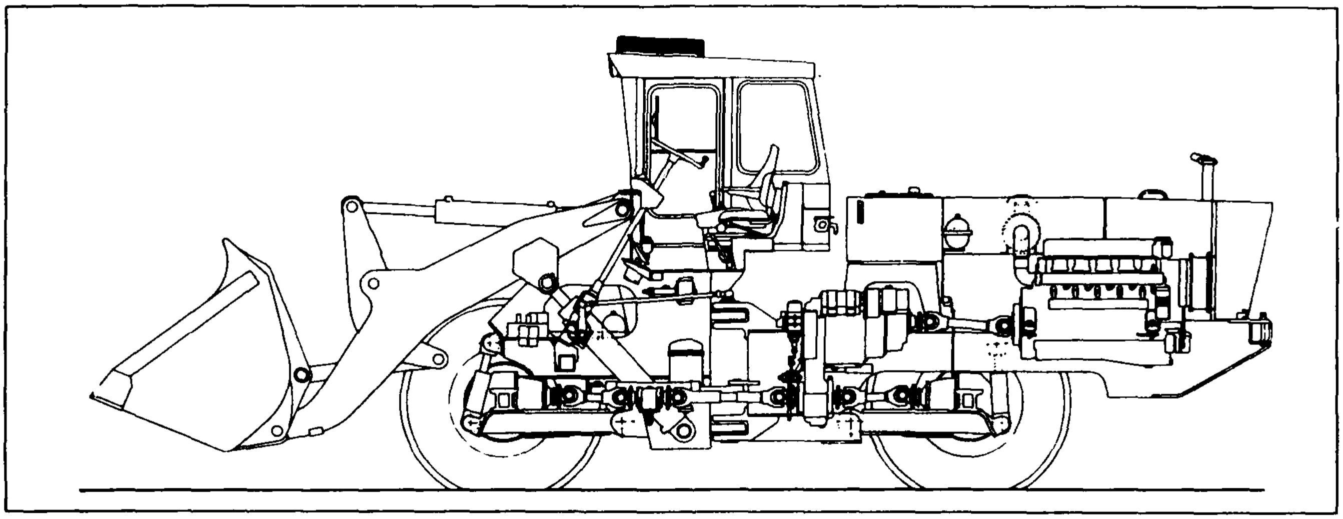


FIGURE 4. ZETTELMEYER ZL 75C

3.2.2 Unimog Tractors

Mercedes-Benz manufactures a truck-like tractor which is capable of rough terrain operation as well as highway speeds up to 49 mph. The specifications for the larger of the Unimog vehicles, the U1200, are shown in Table 7. Schmidt Engineering and Equipment Co., Ltd., in Milwaukee, WI supplies a 4000 lb. capacity forklift attachment for the Unimog with a ten foot mast.

The Unimog is a truck-like vehicle with a coil-spring suspension on both axles and Ackerman steering on the front axle. The suspension cannot be stiffened for operation in the working mode. Thus, forklift operation could be expected to produce significant deflections on the suspension.

Also, assuming that the forklift attachment is placed on the front of the vehicle where the operator can see the work area, the weight distribution will be adverse for forklift operation. It is likely that counterweight will have to be added to the rear bed of the vehicle.

3.2.3 Trantor Vehicles

Trantor International, Ltd. of Stockport, England has developed two vehicles for agricultural tractor and transport work. One of these has a four-wheel drive option. The specifications for both basic vehicles are similar; those for the higher power version are shown in Table 8.

These vehicles are similar to agricultural tractors except that both axles are sprung from the frame. The front beam axle is supported on coil springs and the rear axle on leaf springs. There is no provision to lock out the suspension when operating in the work mode.

The vehicles have 10 (5x2) forward speeds and are capable of a top speed in the 45 to 48 mph range in the top range.

TABLE 7

UNIMOG 1200 - SPECIFICATIONS

Mercedes-Benz Unimog Tractor U1200 (424)

Technical Specifications

Engine

Make	Mercedes-Benz
Model	OM 352
Displacement	346 in³ (5675 cm³)
Bore and Stroke	3.819" x 5.039" (97 mm x 128 mm)
Number of Cylinders	6
Compression Ratio	17:1
Fuel	No. 2 Diesel
Fuel Supply	Bosch Injection Pump
Air Cleaner	Dry Type
Oil Filter	Combination Full and By-Flow
Horsepower	
Gross Rate	130 @ 2800 rpm (96 kW @ 2800 rpm)
*SAE Net	120 @ 2800 rpm (88 kW @ 2800 rpm)
Max. Torque	268 ft. lbs. @ 1700 rpm (363 Nm @ 1700 rpm)

*Net of engine when applied to this vehicle when equipped with operating accessories including oil, water and fuel pumps, alternator, air cleaner, fan and muffler. Corrected to 500 ft. (152 m) altitude with .38 in (9.5 mm) Hg vapor pressure; 29.39 in (746 mm) Hg observed barometer and 85°F (29°C) air (per SAE J816a specifications).

Hydraulics

Design	Independent
Oil Pump	Gear Pump with Needle Roller Bearings
Pump Delivery	11.9 gpm (45 liter/min.) @ 2530 rpm Engine Speed
Operating Pressure (Max.)	2840 psi (200 Bar)
Controls	4 Double Acting Control Valves for Alternate Operation of Hydraulic Rams via Front And Rear Hydraulic Connections
Three Point Hitch System	
Category	II
Hitch Capacity	8820 lbs. (4000 kg)

Operational Data

Driving Speed @ 2800 rpm Engine Speed (6.527 Axle Ratio and 12.5R20 Tires)

	8 x 8 Trans.		16 x 16 Trans.		24 x 24 Trans.	
	High Range Gears		Working Gears		Crawler Gears	
	mph	km/h	mph	km/h	mph	km/h
Forward 1st	5.3	8.4	0.91	1.5	0.094	0.15
2nd	7.3	11.6	1.3	2.0	0.13	0.21
3rd	10.0	15.9	1.7	2.8	0.18	0.29
4th	13.5	21.6	2.3	3.8	0.24	0.39
5th	19.0	30.4	3.3	5.3	0.34	0.54
6th	26.4	42.2	4.6	7.3	0.47	0.75
7th	36.1	57.7	6.3	10.0	0.65	1.03
8th	49.1	78.5	8.5	13.6	0.88	1.40

Driving speed in reverse = driving speed in forward x 1.03

Electrical System

Battery	12V/110 Amp/h.
Alternator (three-phase current)	14V/55 Amp (770 W)
Starter Output	4 hp (4 ps)

Note: All specifications are stated in accordance with ICED Definitions of SAE Standards or Recommended Practices, where applicable

Important: Mercedes Benz reserves the right to change these specifications without notice and without incurring any obligation relating to such changes

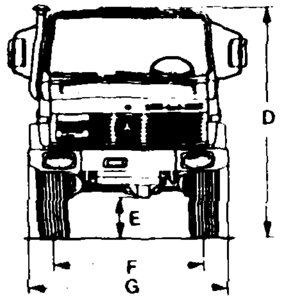
TABLE 7 (Continued)

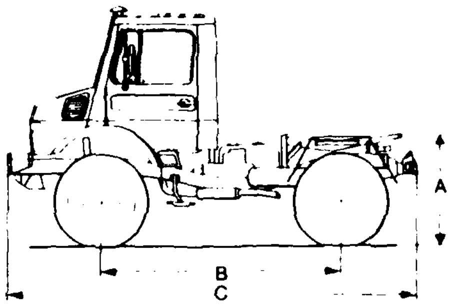
UNIMOG - 1200 SPECIFICATIONS

Mercedes-Benz Unimog Tractor U1200 (424)

Technical Specifications

Measurements in. (mm) Unladen Tires 12.5R20/12PR





Tractor Dimensions

(A) Platform Height	52.0" (1320 mm)
(B) Wheelbase	104.3" (2650 mm)
(C) Overall Length	176.0" (4470 mm)
(D) Overall Height	102.8" (2610 mm)
(E) Ground Clearance	
(under differential)	17.3" (440 mm)
(under axle)	21.3" (540 mm)
(F) Track Width 12.5R20" Tires	71.2" (1810 mm)
10.5R20" Tires	62.4" (1585 mm)
(G) Overall Width	83.1" (2110 mm)

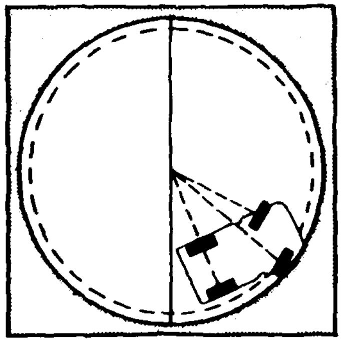
Weight with Tires (12.5R20/18PR)

Dead Weight	9,920 lbs (4500 kg)
Total Maximum Weight (with Attachments)	16,500 lbs (7500 kg)
Permissible Axle Load (front and rear)	9,700 lbs (4400 kg)

Note: Max. weight of 16,500 lbs. is based on an expected road speed of 49.1 mph. If vehicle exceeds 16,500 lbs., the 49.1 mph speed may not be attained.

Turning Circle

Minimum Track Dia. (outer track)	34'9" (10.6 m)
Minimum Swept Dia.	39'4" (12.0 m)



Capacities

	Quarts	Liters
Cooling System	18.9	20.0
Lubricants		
Engine with Oil Filter	14.2	15.0
Hydraulic System (Oil Tank Only: 18L)	33.1	35.0
Steering Gear Housing	1.00	0.9
Power Steering	2.1	2.25
Standard Gearbox	9.0	9.5
Working Group	10.9	11.5
Crawler Group	11.8	12.5
Front and Rear Axle Housing-Each	2.37	2.5
Wheel Hub Drive (4)-Each	0.5 Pint	0.25
Brake Fluid		
Braking System	1.9 Pint	1.0
Clutch System	0.4 Pint	0.2
Fuel		
Fuel Tank	34.34 Gals.	130

Power Take-Off

PTO—Front and Rear	
Splined Shaft Section	1.75" (44.45 mm)
Two-Speed	540 rpm @ 2200 rpm engine speed 1000 rpm @ 2300 rpm engine speed
Power Output	108 hp (80 kW)
Front and Rear PTO Requires Center PTO	
Center PTO	Power Take-Off Via Chain and Sprocket; Speed and Direction of Rotation as Per PTO
High Capacity PTO	
Ratio 1:1 for cranes and backhoes (N16) ccw rotation	
Ratio 1:1.41 for water pumps (N17) cw rotation	

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TABLE 8

TRANTOR 1262 - SPECIFICATION

ENGINE

Model Type	Perkins 6.3544 Direct injection. Naturally aspirated, four stroke, six cylinder, water cooled diesel engine.
Bore	98.4mm (3.875)
Stroke	127mm (5.00 in)
Swept volume	5.8 Litres (354 cu.in.)
Compression ratio	16:1
Firing Order	1,5,3,6,2,4
Rotation	anti clockwise looking at flywheel end
Full load speed range	650 to 2800 rpm
Lubrication system	Wet sump
Air compressor	Clayton Dewandre SC6 water cooled
Max BHP	126 at 2800 rpm BS AU 141a
Max torque	276 ft at 1,500 rpm BS AU 141a
Filters	Oil - *paper element* Air - Dry paper cartridge
Cooling system type	Water circulation through block by means of thermosyphon and water pump. Thermostat opens at 85°C, system pressurised by a relief valve set at 7lb pressure (3.5kg) and located in the radiator cap.

Clutch

Type	Borg and Beck 13" (33cm) diameter single plate heavy duty clutch operated by a cable from the foot pedal.

TRANSMISSION

Main gearbox type	Eaton model 475 SMA Mk IV 5 speed synchromesh
Ratios:	1st gear 1:6:92 2nd gear 1:3:98 3rd gear 1:2:38 4th gear 1:1:47 5th gear 1:1 Reverse 1:6:81
Transfer gearbox type	2 speed all helical box, containing pto reduction gears when fitted
Ratios:	High 1:1:28 Low 1:3:45
Differential type	Eaton type 1300, 6.33:1 reduction with diff lock

POWER TAKE OFF

Type	Full power, 2 speed, non live pto with low power live option. Approx 105 hp developed at 540/1000 rpm
Size	Six spline 1 3/8" diameter

HYDRAULIC POWER

Hydraulic pump	Independant gear pump
Max pressure	2850 psi (190 bars) circuit relief set at 2500
Max delivery	9 gallons per minute (50 litres per min)
Hydraulic tank capacity	11 gallons (50 litres)
Hydraulic couplings	Self seal extractor couplings *on flow and* return unions.

DRAWBAR

Movement	8" (204mm) either side from centre line
Rec. static laden capacity	2.0 tonnes

POWER LIFT

Type	Detachable category 2, 3 point linkage with facility to suspend implements for fast transit.
Rec. max. working load before additional front weights required	2.5 tonnes at end of links

BRAKES

Front brakes	12.25" x 2.5" (311mm x 63.5mm)
Rear brakes	13.0" x 5.5" (330mm x 140mm)
Type	Separate hydraulic systems with separate master cylinders activated by air diaphragm units controlled by a dual brake valve.
Hand brake	Operates on rear wheels via spring servo and cables
Independant rear wheel brakes	2 further master cylinders activated by air *diaphragms controlled by floor mounted* push buttons, as standard

STEERING

Type	Power assisted. Adwest steering box
Steering lock	2¾ turns of the wheel lock to lock
Turning circle	34 ft (10.6m) without brakes

SUSPENSION

Front type	Coil sprung, beam axle located by 2 leading radius arms and panhard rod with telescopic shock absorbers.
Rear type	Eleven leaf springs 2 ¼" x ¼" (57mm x 6.5mm) with telescopic shock absorbers. Located on four trailing radius arms.

TYRES

Standard front	10.50 x 18, 8 ply rating
Standard rear	16/70 x 24, 14 ply *rating incorporating* water filler valve.
Optional rear	15 x 28 14 ply rating
Also available	2 alternative low ground pressure tyre sets Double rear wheel mountings.

ELECTRICS

Standard circuit	12v negative earth incorporating full road lighting interior and rear working lights, 2 speed heater fan, 2 speed self park wipers and screen wash.
Optional	Cab pressuriser unit, radio, clock

AUXILLIARY SERVICES

Air	2 line system with self sealing couplings to trailer
Hydraulic	Single, double acting, continuous supply and return to tank, outlets to implements fitted as standard.

TABLE 8 (Continued)

TRANTOR 1262 - SPECIFICATION

HITCH

Type	Patented independently sprung self-levelling pick-up hitch, with facilities to replace standard pick-up hook with swinging drawbar. Positive hook snap latch controlled from drivers seat.
Rec. static laden capacity	3.75 tonnes
Lifting height	18.5" (470mm)

DIMENSIONS

Wheel base	100" (2540mm)
Overall length	166" (3607mm)
Overall width	81" (2057mm)
Overall height	92" (2337mm) unladen
Ground clearance (front axle)	15.5" (394mm) with standard wheels
Ground clearance (rear axle)	14.0" (356mm) with standard wheels

WEIGHT

Approximately 3.2 tonnes unladen

These vehicles could be fitted with a forklift mast on their rear end. However, the controls and operators position would have to be reversed for ease of operation. Unless two operator positions were provided, this would produce a front or four-wheel drive, rear wheel steer vehicle for highway operation.

The weight of this vehicle and the driveline design,which makes use of truck-type axles without a planetary final drive, would place it in the 4K RTFLT range.

3.2.4 Truck-Mounted Machines

There are a number of truck mounted machines which can achieve a high travel speed on the highway and rough terrain operation at the work site. Two examples are provided by the Gradall G3WD (4x4) boom excavator and the Harnischfeger Omega S All-Terrain crane.

Both of these vehicles are capable of highway speeds of 45 mph or more. The G3WD has an unsprung rear axle and a leaf-spring suspended front axle. The Omega S suspends both axles on leaf springs. However, both vehicles allow the suspension to be locked out by the hydraulic shock absorbers when operated in the work mode.

The G3WD has front wheel Ackerman steering, and the Omega S has four wheel Ackerman steering which can be used in either the synchronized or crab steer mode.

These types of vehicles would be most suitable for modification to an extending boom-type of forklift like the 6K VRRTFLT.

Harnischfeger also has developed an active system that uses a truck-mounted crane hoist cylinder and boom to resist the bounce and pitch oscillations of the vehicle while travelling between work sites. This system, which is called "Easy Ride", stabilizes the motion of the vehicle by operating against the inertia of the boom.

3.2.5 Standard Trailing Arm Drive

Standard Manufacturing Co., Inc., of Dallas Texas has developed a skid steer trailing arm drive chassis which could be used as a platform for a rough terrain forklift.

The vehicle chassis is shown in Figure 5, and the specifications for the 8W12 model are listed in Table 9. The concept has been applied to a number of prototype military vehicles with a speed capability of up to 55 mph on maintained surfaces. Chassis capacities are evidently available up to 100,000 lbs. GVW so they cover the entire range of interest.

The wheels are driven by hydrostatic drives through roller chains on either side of the vehicle and are steered by skid-steer or speed variation between sides.

Each wheel is suspended on a trailing arm which is supported by a coil-spring shock absorber assembly. A hydraulic cylinder is also provided to allow independent raising and lowering of the wheels. Presumably these cylinders could also be used to lock the wheels at a specific angle or height for operation in a work mode. By raising the outer wheels slightly, the vehicle can be pivoted about its own center.

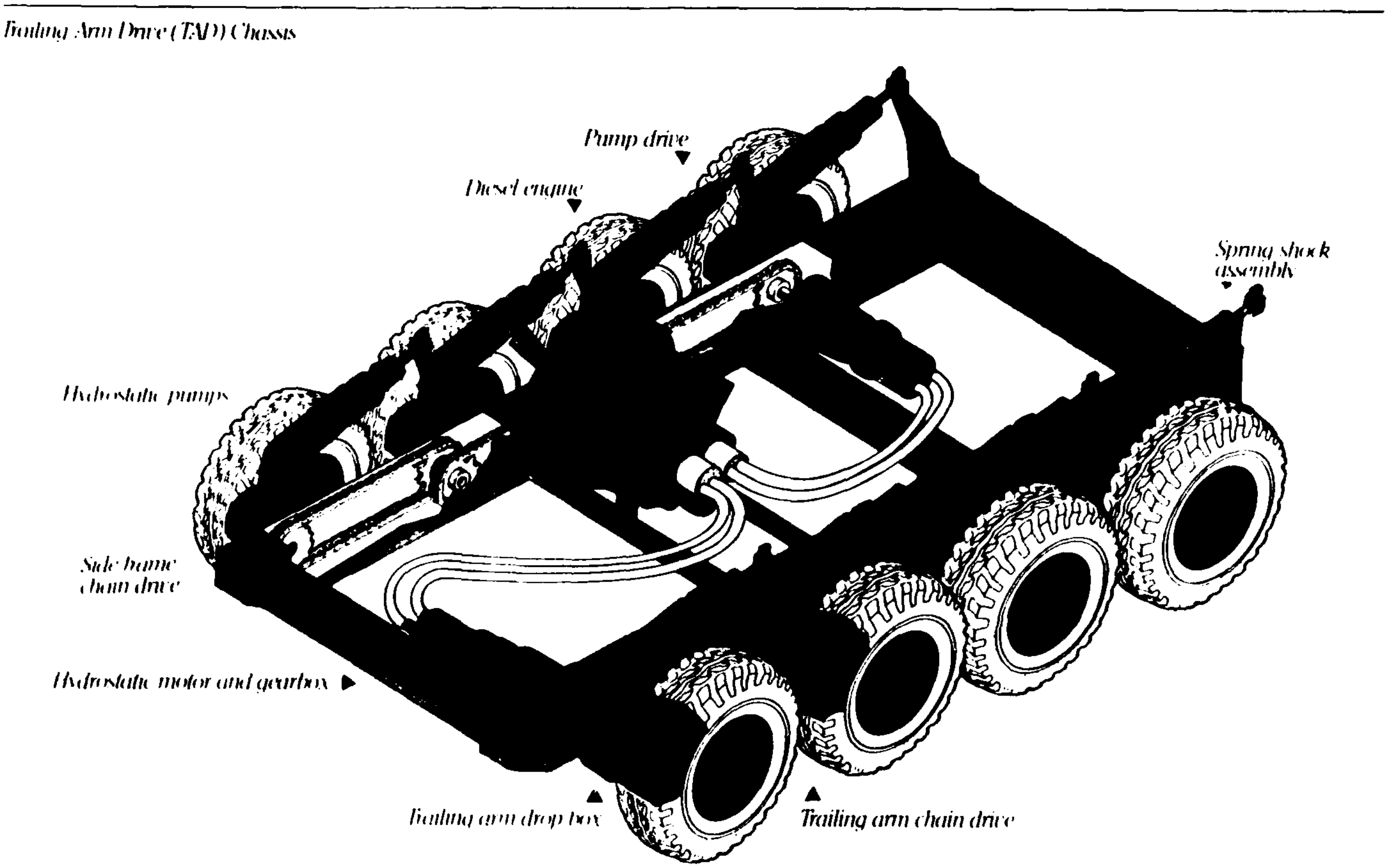

Trailing Arm Drive (TAD) Chassis
Pump drive
Diesel engine
Spring shock assembly
Hydrostatic pumps
Side frame chain drive
Hydrostatic motor and gearbox
Trailing arm drop box
Trailing arm chain drive

FIGURE 5. STANDARD MANUFACTURING CO.
TRAILING ARM CHASSIS

TABLE 9

STANDARD 8W12 CHASSIS - SPECIFICATIONS

Vehicle Specifications

Model	**8W12**
Weight (Empty)	11.000 Lbs.
Weight (G.V.W.)	18.000 Lbs.
Payload Capacity	7.000 Lbs.
Drive System	All-Wheel Hydrostatic
Suspension System	8-Wheel Independent Trailing Arm Drive
Steering	Pivot Automotive Type Control
Overall Dimensions	
Length	213"
Width	102"
Height to Top of Cab (Variable)	73" maximum 61" minimum
Variable Ground Clearance	10 Inch to 22 Inch
Brakes	Hydrostatic Braking and All Wheel Power Disc
Lights	Combat Service with Blackout Feature
Operating Pressure	
Drive System	6.000 psi
Wheel Positioning System	2.000 psi
Brake System	1.500 psi
Charge System	350 psi

Speed Range	0-45 M.P.H.
Engine:	
Model	Detroit Diesel 6.2 Liter
Type	4 Cycle 8 Cylinder Diesel
Horsepower	150 H.P. @ 3.600 rpm
Hydraulic Fluid	SAE 10W Per MIL-L-2104
Fuel Tank Capacity	50 Gals.
Hydraulic Tank Capacity	25 Gals.
Tires	36 12.50-16.5 Equipped with Run Flat Devices and Central Tire Inflation on all wheels
Tire Pressure	35 psi
Ground Pressure	8.9 psi
Slope Negotiation	60% Longitudinal 40% Side Slope
Towing Capability	Vehicle of Equal Weight

Trailing Arm Drive vehicles are available in sizes ranging from 4000 lbs. GVW with 1500 lbs payload to 100,000 lbs GVW with 50,000 lbs payload

4. LITERATURE REVIEW

A computer search was conducted covering the major engineering and government data bases for the period between approximately 1964 and 1986. Key subject areas were off-road vehicles, industrial vehicles, and military vehicles, and including subareas such as high-speed capability, suspension systems, and steering. An extensive list of citations and abstracts resulted from the search.

However, the bulk of these concerned high mobility off-road applications and agricultural operations where the maximum speeds are much lower than 45 mph. For example, Holm (5) reviews the performance characteristics of a wide range of wheeled, articulated vehicles but does not address speed problems or the details of the suspension systems.

Janowski (6) describes a high-mobility, high-speed vehicle, the Lockheed Twister. This vehicle is an 8x8 vehicle with a three degree-of-freedom articulation. In addition, it incorporates a coordinated Ackerman steering system on the front wheels. The rear tandem axles are supported on a walking beam suspension, and the front axles are independently sprung. The vehicle is capable of extremely high mobility on rough terrain, including 60% gradeability and 30-inch obstacle capability. It is also capable of 55 mph over the highway. This degree of mobility, of course, is not required for rough terrain forklift operations, but the vehicle shows that high speed stability can be attained with an appropriate suspension system and that articulation does not inherently limit high speed highway operation.

Watson (7) describes a tandem axle truck suspension using a combination of cantilever and torsion springs for operation both on and off the highway. Specific requirements included large vertical motion, increased roll stability, and non-linear spring rate.

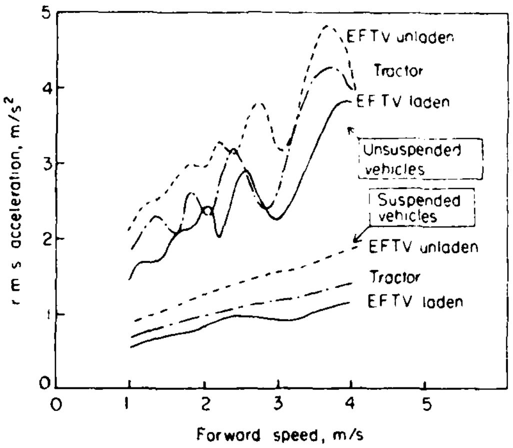
A number of papers were found which deal with off-road vehicle ride characteristics. Claar, et al., (8) provide an excellent summary of a number of vehicles, primarily agricultural, which use a variety of suspension systems to control operator shock and vibrations. Seat, cab, front axle, and two-axle suspension systems are described. However, high-speed highway operation is not specifically discussed. In a separate paper, Claar et al., (9) describe an analytical design method for simulating a generalized tractor suspension and selecting the design parameters.

Active seat suspensions are described by Young and Suggs (10) and Hall (11). These systems use a hydraulic servo system to isolate the seat from the vehicle motion.

A number of papers were found which deal with methods for characterizing road roughness. (12-15) These papers describe measurement methods and spectral characterization techniques. However, none include typical data for improved or paved roads.

A considerable body of literature has been published by D. A. Crolla, et al., at the University of Leeds in England. (16-21) This work concerns both ride dynamics (vertical oscillation) and steering or lateral dynamics. Most of the discussion, and quantitative solutions relate to agricultural vehicles. However, the types of vehicles, especially in the case of articulated body-steer tractors, are similar to the cases of interest here.

In the case of ride dynamics, Crolla has analyzed both an Ackerman steering tractor and an Experimental Farm Transport Vehicle (EFTV). (21) The latter is a truck-like vehicle, which steers by articulation between the front and rear chassis, has an active suspension and is capable of 65 Km/hr. (40 mph). The characteristics of these vehicles and their RMS vertical accelerations when simulated with and without suspension system up to 5 m/s (11 mph) are shown in Figure 6. (21) The RMS vertical accelerations of suspended vehicles up to road speeds of 25 m/s (56 mph) are shown in Figure 7 (21). It can be seen that the RMS accelerations of the suspended vehicles are in the order of 1 m/s^2 (0.1g) in the range of 45 mph. This is a reasonable range of acceleration. However, the comparison between



Data for vehicles used in ride vibration predictions

	Tractor	*EFTV unladen*	*EFTV laden*
Body mass, kg	4000	4000	5000
Body pitch inertia, kg m^2	5000	8000	18.000
Front axle mass, kg	250	500	500
Rear axle mass, kg	750	500	500
Wheelbase, m	2·4	3·6	3·6
Distances (see *Fig. 4*)			
x_f, m	1·0	1·6	1·9
x_r, m	1·4	2·0	1·7
x_s, m	0·6	1·4	1·7
z_s, m	0·5	0·5	−0·1
z_g, m	0·9	0·9	1·5
Tyre properties (per axle)			
k_x, kN/m	900	900	900
k_z, kN/m	900	900	900
c_x, kN s/m	5·0	5·0	5·0
c_z, kN s/m	5·0	5·0	5·0
Suspension properties (per axle)			
k_s, kN/m	400	400	400
c_s, kN s/m	20	20	20

FIGURE 6. COMPARISON OF THE VERTICAL ACCELERATIONS OF THE DRIVER'S SEAT FOR TWO VEHICLES.

(Adapted from Ref. 21)

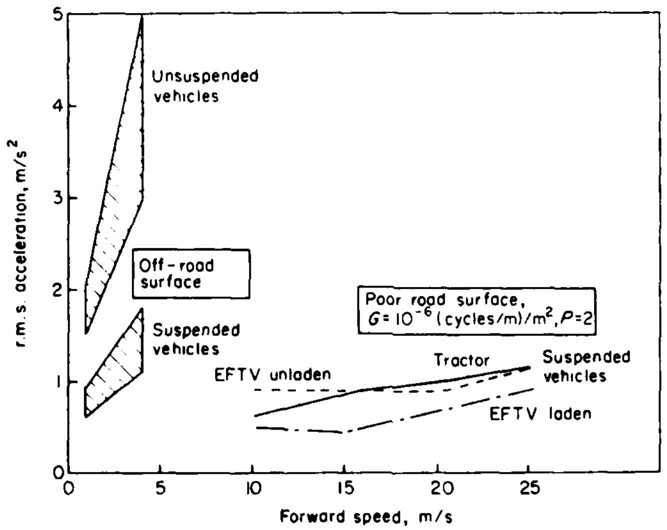


FIGURE 7. PREDICTED R.M.S. VERTICAL ACCELERATION OF DRIVER'S SEAT FOR THE VEHICLES AT HIGHER SPEEDS ON A POOR ROAD SURFACE.

(Adapted from Ref. 21)

suspended and unsuspended vehicles at speeds up to 5 m/s (11 mph) suggests that at high speeds the unsuspended vehicle would not be acceptable. This comparison is even more vivid when examined in the frequency domain. Figure 8 shows the vertical acceleration spectral density of the unladen EFTV as a function of frequency for a speed of 2 m/s and a ground roughness coefficient of 10^{-5} which is typical of agricultural situations. It can be seen that the response of the principal resonant mode decreases from about 10 $(m/s^2)^2$/Hz as various degrees of suspension are added. (19, 20)

Crolla and Hales describe the lateral stability of the related tractor-trailer combination in Reference (16) and Crolla and Horton present an excellent summary of the lateral stability of an articulated tractor and farm transport vehicle in Reference (18). In the latter work, they summarize the equations of motion for the four-degree-of-freedom system including articulation angle. Linearizing these and making small angle assumptions, they calculate the eigenvalues or roots as a function of forward speed. The characteristics of the two vehicles are shown in Table 10 where the dimensions used are shown in Figure 9. It can be seen that these are 3000 kg (6600 lb.) vehicles unloaded. The parameter, C , is a tire side force characteristic, and k_R and c_R are the torsional stiffness and damping, respectively, of the articulated hinge.

The results are shown in Figures 10 and 11 for the two vehicles as a function of speed. When the dotted (oscillatory) root is on the axis or in the positive quadrant, the system would exhibit a weave oscillation. When the solid (exponential) root crosses into the positive quadrant, the system would be expected to fold or jackknife around the articulation joint.

For the tractor, which may be closest to the configuration of interest in this study, the basic case of Figure 10 (a) shows the onset of jackknifing at 12 m/sec. (27 mph). If the c.g. of the forward section is moved forward, as shown in Figures 10 (b) and 10 (c), stability is improved considerably and the critical speed increases to above 20 m/sec. (45 mph). This suggests the surprising possibility that a forklift truck may be more stable if run loaded at high speed.

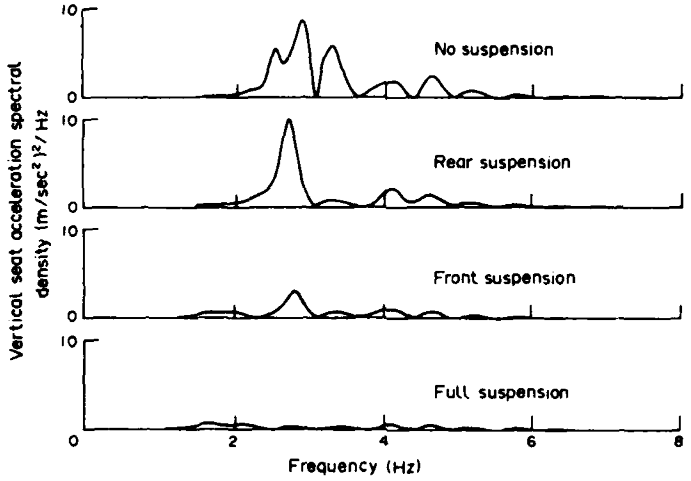


FIGURE 8. PREDICTED POWER SPECTRAL DENSITY VERTICAL ACCELERATION AT THE DRIVER'S SEAT OF A FARM TRANSPORT VEHICLE LAYOUT FOR DIFFERENT SUSPENSION OPTIONS.

(Adapted from Ref. 20)

TABLE 10

DATA USED FOR THE LATERAL STABILITY ANALYSIS OF REF. (18)

	Typical articulated tractor	Farm transport vehicle	
		unladen	laden
m_1 kg_2	1500	1500	1500
I_1 kg m^2	1500	1000	1000
m_2 kg	1500	1500	7500
I_2 kg m^2	1500	1500	7500
x_{1F} m	0.6, -0.1, -0.6	0.3, 0, -0.3	0.3 0, -0.3
x_{12} m	0.6, -1.3, -1.8	-0.35, -0.65, -0.95	-0.35, -0.65, -0.95
x_{21} m	0.6, 1.3 1.8	1.55	1.55
x_{2R} m	0.5, 0.1 0.6	-1.5	-1.5
C_α rad^{-1}	3.4	3.4	3.4
k_R Nm/rad	50 000	50 000	50 000
c_R Nms/rad	0	0	0

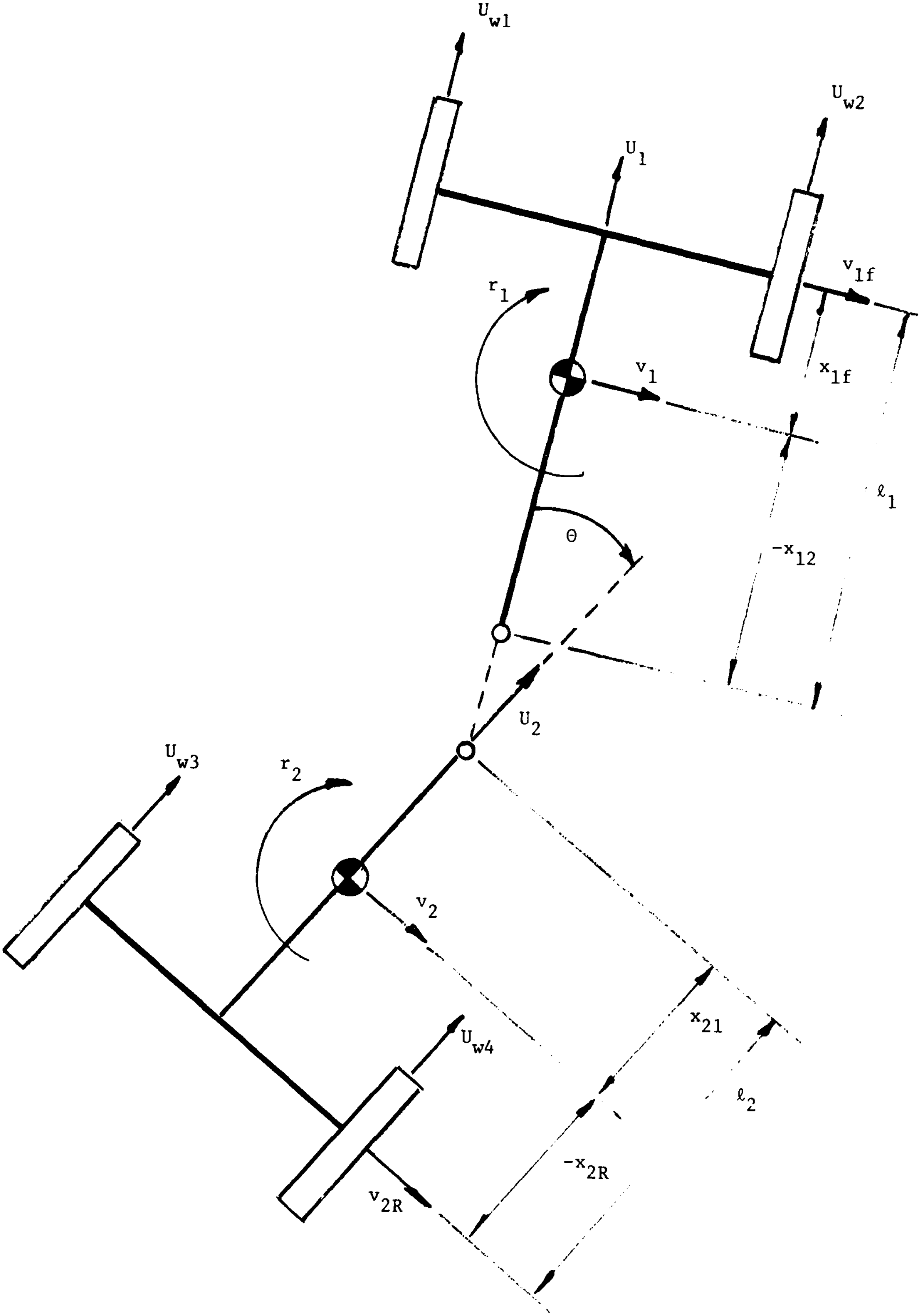
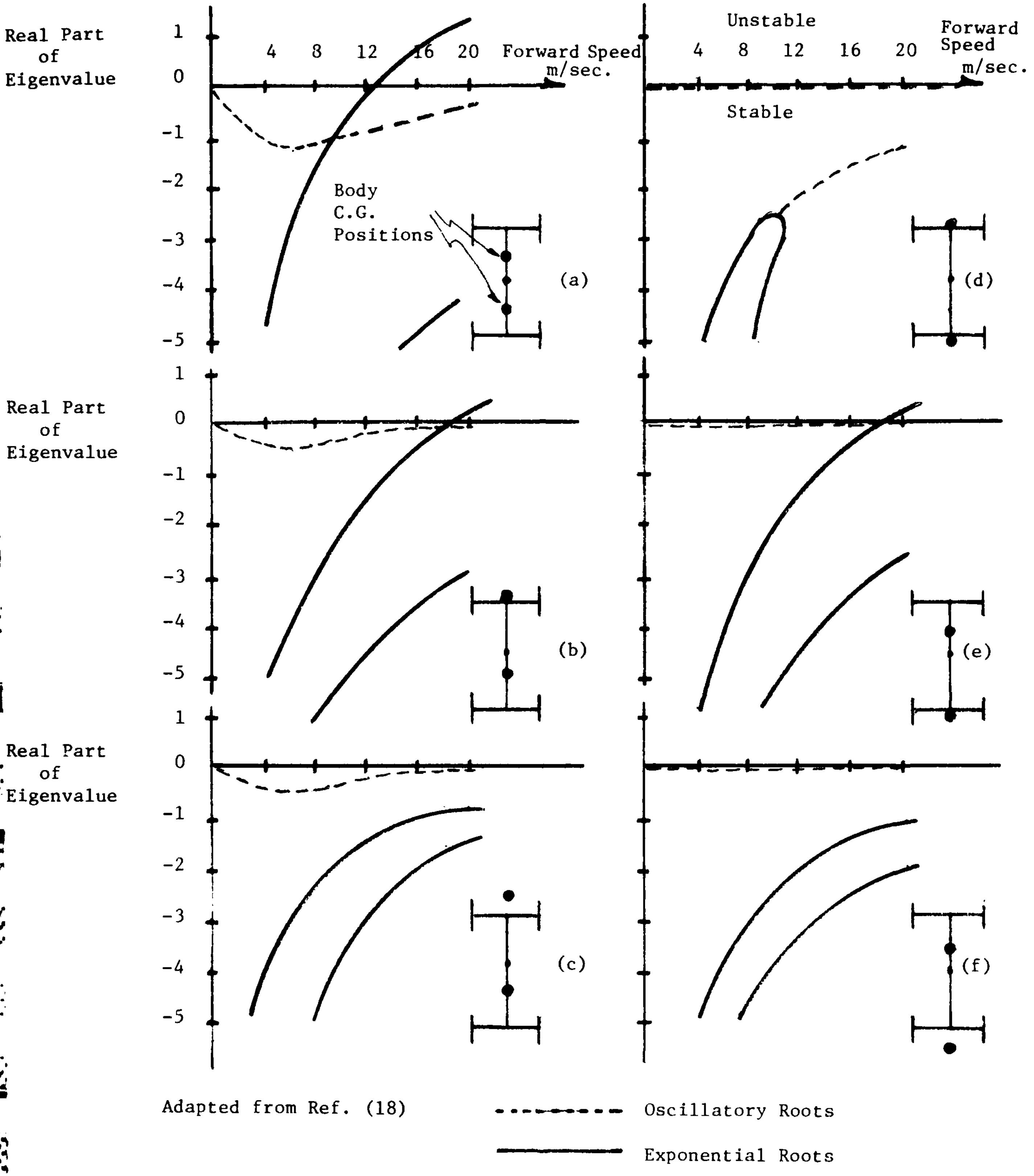

U_{w1}
U_{w2}
U_1
v_{1f}
r_1
x_{1f}
v_1
ℓ_1
Θ
$-x_{12}$
U_2
U_{w3}
r_2
v_2
x_{21}
U_{w4}
ℓ_2
$-x_{2R}$
v_{2R}

FIGURE 9. DIMENSIONS USED FOR THE ANALYSIS OF REFERENCE (18)



Adapted from Ref. (18)

FIGURE 10. EIGENVALUE RESULTS FOR VARIOUS C.G. POSITIONS, ARTICULATED STEER TRACTOR

For the cases of Figures 10 (d), (e), and (f) where the c.g. of the rear section is located behind the wheels, there is an undamped oscillatory root which suggests that weaving motion will be very difficult to control.

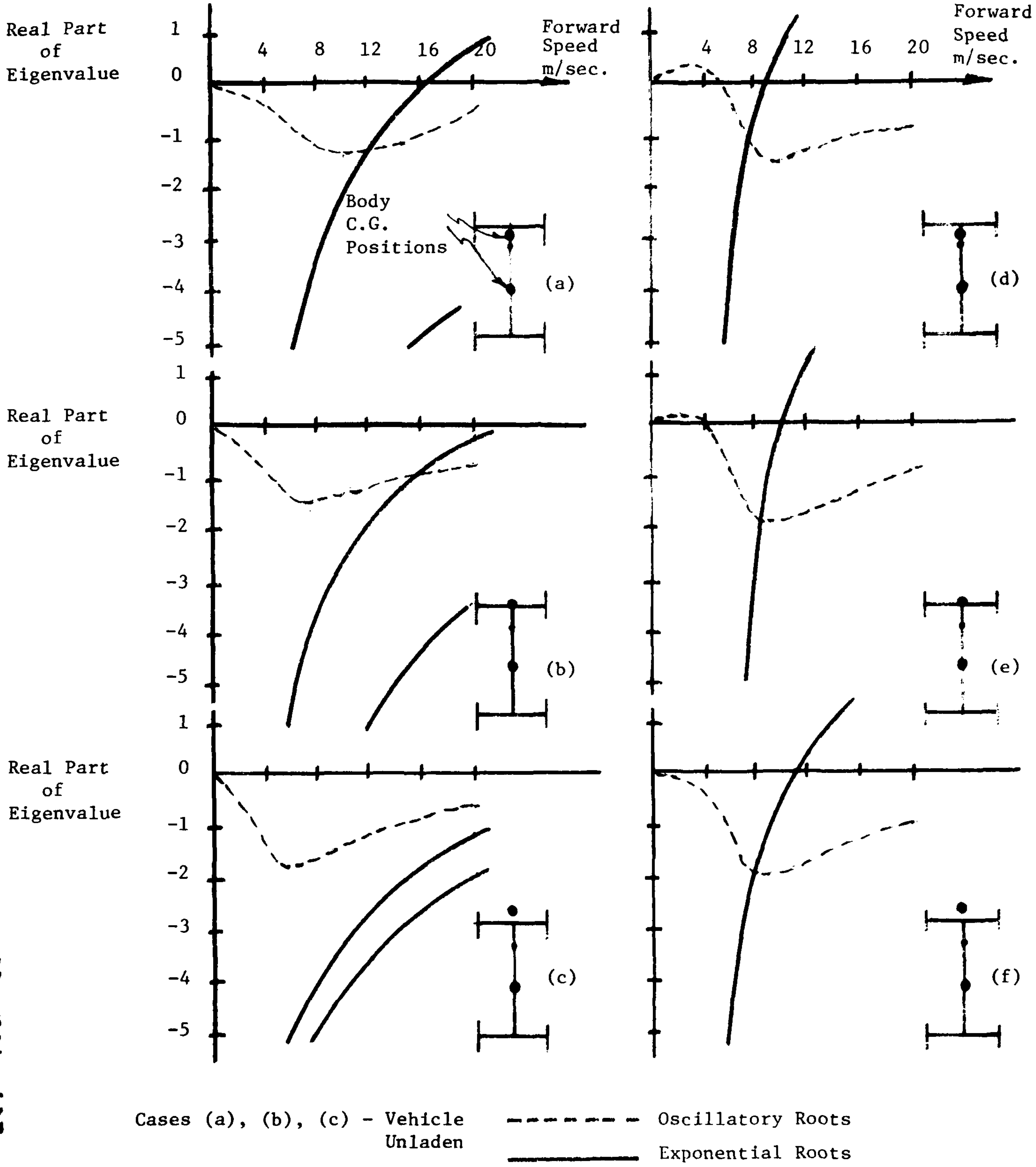
The results for the farm transport vehicle shown in Figure 11 would apply for an articulated forklift configuration with asymmetrical sections. Here, the unladen behavior is similar to the conventional tractor but with improved stability. However, when laden, the vehicle shows an abrupt jackknifing transition at relatively low speed. Also, there appears to be a weaving instability at very low speeds which becomes stable at higher speeds or if the weight of the front section is moved forward.

In summary, the literature review shows that practically no experience can be examined for the behavior of off-road vehicles operating on the road at speeds in the 45 mph range. This is especially the case for heavy articulated vehicles. The survey of existing vehicles covered in Section 3 showed that the only existing articulated vehicles approaching this range are the Zettelmeyer wheel dozers and loaders which operate slightly under 40 mph. No quantitative descriptions of their performance at these speeds was available.

Several lighter dual-purpose vehicles with Ackerman steering, such as the Trantor and the Unimog, have been described in the literature.

However, no experience is available concerning unsprung vehicles operating at 45 mph. The closest experience seems to be a special version of the J.I. Case MC4000 forklift truck which was capable of 45 mph. This vehicle was reportedly very difficult to control on a road or track at this speed and subject to "porpoising" or pitch vibrations. However, no experimental data or formal evaluation was offered concerning its behavior.

Dynamic modelling of both ride quality and handling characteristics has been performed by a number of investigators on vehicles similar to the type of interest. There are no specific quantitative results available in



Cases (a), (b), (c) - Vehicle Unladen

Cases (d), (e), (f) - Vehicle Fully Laden

Adapted from Ref. (18)

FIGURE 11. EIGENVALUE RESULTS - FARM TRANSPORT VEHICLE

the literature which can be specifically applied to the design of these vehicles. However, the available results suggest that a suspension system will be necessary to limit vehicle vibrations and maintain positive wheel loads. The results also suggest that careful attention will be required to the dynamic characteristics of the steering system for articulated vehicles at these speeds and that weaving, although controllable, may not be entirely avoidable.

5. IDENTIFICATION OF PROBLEM AREAS - PHASE I

5.1 ESTABLISHMENT OF POTENTIAL PROBLEMS

At the outset of the program, conferences were scheduled with technical personnel at manufacturers which currently manufacture the Army forklift trucks described in Section 3. In addition, meetings or telephone conferences were held with a large number of other manufacturers of off-road vehicles or components, some of which are discussed in Section 3. The objective of all of these discussions was the identification of potential problem areas for high speed operation on the road. These areas would then be investigated in greater detail in subsequent tasks by analysis and state-of-the-art assessments.

As a result of these discussions and the information in the literature discussed in Section 4., a consensus was soon reached as to the major potential problem areas. The problem areas and the specific questions to be addressed in each area are discussed in the following subsections.

5.1.1 Vertical Dynamics

It was generally held by all vehicle designers consulted that vertical dynamics would be a problem at 45 mph. In particular, it was expected that vertical vibrations or "hop" and pitch vibrations, "porpoising" or "dive," would be critical.

This expectation is based largely on the fact that, even at 20 mph, most of these vehicles exhibit significant oscillations. Also, the analytical studies discussed in Section 4. suggest that vehicle oscillation is critical at high speeds and reduces considerably when a suspension system is introduced.

In this study no quantitative study was found dealing with 45 mph operation of a vehicle in any of the forklift classes. Moreover, none of the manufacturers had tested or instrumented a vehicle in this speed range with the exception of the special Israeli MC4000 discussed in Section 3.1.1.

However, it is also significant to note that no vehicle, other than the Israeli MC4000, was identified which operates at any significant speed above 20 mph without some type of wheel or axle suspension system in addition to tire compliance.

Excessive vertical and pitch vibrations can have several major effects:

(a) violent vibrations can cause injury to the driver or cause him to lose control of the vehicle;

(b) high accelerations will impose inertial loads on all components causing malfunction and failures, especially structural failures;

(c) vertical and pitch vibrations cause loss of contact between the tires and the road, again affecting the ability of the driver to control the vehicle.

Thus, it is clear that this is a significant problem area for high speed operation and warrants additional study and analysis.

5.1.2 Handling Characteristics

Handling is generally expected to deteriorate at higher speeds. In the preceding section, it was noted that excessive vertical and pitch vibrations can lead to unloaded wheels which can affect handling by reducing or eliminating possible steering forces.

All of these vehicles have poor roll-over stability. The ratio of the height of the center-of-mass to the track is much higher than most highway vehicles (i.e. 0.85 to 1.5 compared with 0.65). The pivoted axle shifts almost all of the lateral weight transfer in a turn to the rigid axle which likely accentuates the oversteer characteristics of the articulated vehicles and understeer of the rear wheel steer vehicle.

Because the roll axis is steeply inclined, high lateral force in a turn is likely coupled to pitch and it may be expected that the pivoted axles will jack under high lateral forces causing the inside wheel to unload and lift off the surface.

If there is any clearance or compliance in the articulated joint, articulated steering tends to produce excessive gain. Front wheel lateral forces tend to increase the joint deflection and tighten the turn.

The work of Crolla (16, 18), discussed in Section 4., clearly shows that articulated vehicles exhibit potential lateral instabilities which can lead to jackknifing or weaving. These instabilities are speed dependent and are expected to appear as certain critical speeds are attained.

Again, no specific test or analytical data could be found for the vehicles of interest or vehicles having similar characteristics. However, it is clear from the information available that this will be a problem area of concern for the articulated high speed vehicles in the M4K and M10A category.

The specification for the 6000 lb. VRRTFLT calls for Ackerman steering.(3) To get the short turning radius required for this type of vehicle with Ackerman steering, many off-road vehicles use four-wheel coordinated steering. Both front and rear axles are, thus, steering axles. In this case, little additional complexity is required to select four-wheel crab, two-wheel front, or two-wheel rear steering on alternative modes. The use of two-wheel front, or conventional, Ackerman steering for highway operation would be expected to provide the minimum handling problems at high speed. For example, the exponential or jackknifing mode of instability described in Section 4. would not be possible. Also, the inertia and slower response expected in an articulated machine would be eliminated.

However, the use of Ackerman rear steering, as is currently used on the Gradall 543B, for highway operation is expected to produce many handling problems. Rear end breakaway recovery capability is expected to be poor on all of these vehicles but non-existent on the rear-wheel steer vehicle. To reduce the rear slip angle and regain tire traction, it would be necessary to turn in the direction to increase the yaw rate. In fact, the general lateral transient response of the rear-wheel steer vehicle will be unfavorable since yaw damping is the only stabilizing effect and it decreases with speed. Compared with conventional highway vehicles, all three of these vehicles are likely to exhibit poor control quality and operator feedback due to:

- lack of steering spin-back
- lack of steering force gain as lateral force builds up
- no skid warning
- poor breakaway or skid recovery characteristics

5.1.3 Driveline

The design of the driveline for a vehicle of this type inevitably requires a trade-off between the low speed, high effort end of the speed range and the high-speed end of the range.

The stringent gradeability requirement contained in the specifications for these vehicles sets a minimum torque capacity at a speed corresponding to 2 mph for each component in the driveline. For a given vehicle, these requirements are not changed by the addition of a 45 mph top speed capability.

However, the 45 mph requirement more than doubles the speed requirement at the axle. Depending upon where the ratio changes are accomplished to achieve this increase, substantial increases in speed can occur in several of the components.

For example, the M10A has a total axle ratio of about 24:1. Thus, at 22 mph, the maximum input shaft speed is about 2824 RPM. If upstream speed increases, alone, are used to increase the wheel speed from 22 mph to 45 mph, the input shaft speed would have to increase to 5775 RPM which is an extremely high drive shaft speed. This could lead to critical speed and shaft whip problems.

Most axle manufacturers recommend that the input or pinion shaft speed be kept below 3500 RPM and, in no case, exceed 4000 RPM. The problem is that the pinion bearing becomes starved of oil at speeds above this range. Solution of the problem would require forced or pressurized lubrication which adds the requirement for a pump and lubricant passages. Available axles do not include this feature.

The high shaft speed can be reduced by reducing the overall axle ratio, but this will affect the torque which is available from the engine at the low speed range where the gradeability requirement applies.

Thus, it is clear that potential problems are associated with the selection of the driveline components and the ability to find compromise ratios among available components to achieve both 45 mph and low speed gradeability.

Although not anticipated to be major problems in terms of component availability, it should also be noted that a lock-up torque converter is likely to be needed at 45 mph in order to get sufficient power at that speed. Also, peak power is typically absorbed at the top speed, and losses can be expected to increase significantly at 45 mph compared with 20 mph. Thus, a larger engine will typically be required.

5.1.4 Tires

The type of tires used on Army rough terrain forklift trucks are selected for their traction and flotation on soft ground. They are typically rated at 5 mph and are not rated for highway operation for more than short periods. Thus, at the outset of the study, the availability of suitable tires which could operate at 45 mph on the road was viewed as a potential problem area. This is a problem which must be addressed in terms of component availability alone, of course, since design changes to the vehicle will not alleviate the ultimate requirement for a tire to operate at 45 mph and still be of a size and construction that provides the current load capability and flotation characteristics.

5.2 GENERAL DESIGN APPROACH

At this point it should be pointed out that the vehicle designer might adopt any one of three alternative general design approaches to avoid or overcome the high speed problems identified in the preceding sections:

(a) New Concept - The designer could choose to leapfrog over the design problems with a design approach which eliminates many of them. For example, he could select a basic vehicle chassis design which is proven at 45 mph and add the forklift equipment to this chassis. The Standard Manufacturing Trailing Arm Drive chassis described in Section 3.2.4 exemplifies this type of chassis. Another example would be an all-terrain truck crane chassis with a forklift mechanism instead of a crane.

(b) New Conventional Design - The designer could also choose to apply essentially the same general design as the current vehicles but adopt component changes and refinements which will overcome the problems. An example here might be the Zettelmeyer high speed wheel loader, which is similar to a conventional articulated loader like the M10A, but has suspended axles and other improvements needed for high speed operation.

(c) Modification of Existing Vehicles - It is also possible that one of the existing vehicles can be modified enough to overcome the problems. For example, the frame might be cut away enough to allow the axle or axle beam to be suspended on a compliant suspension.

This study is primarily aimed at approaches (b) and (c) above for the three types of RTFLTs covered by References 1, 2, and 3. However, we would stress the importance of leaving open approach (a) as a promising one for the development of a high speed RTFLT, especially for the larger capacity machines.

5.3 ANALYSIS OF RIDE DYNAMICS

5.3.1 Introduction

It is clear that ride dynamics and suspension design will be critical for a 45 mph RTFLT. The work of Crolla, reviewed in Section 4, on similar, but not identical vehicles, makes this clear. In addition, no successful 45 mph vehicle of this general type has ever been developed without some form of suspension system.

Thus, it is clear that an axle or wheel suspension system will be needed. Because of the need to use final drives for the larger machines and the desirability to use available rigid or steering axles for all machines, the most promising approach will be to introduce a compliant suspension between axle and frame.

It is also clear that to design such a suspension system for any of the three vehicles of interest here would require a detailed layout design program supported by dynamic analysis and followed by an experimental program using laboratory models or a test vehicle. All of this is well beyond the scope of this study.

However, to get a start on determining the general characteristics required of the suspension and the analysis required to size the components, it was decided to develop a simple heave/pitch model of the system. This model is described in the following subsections. Solutions were obtained which allow the preliminary sizing of the possible suspension components.

5.3.2 Description of the Model

The model was formulated to simulate the vertical and pitch motion of a vehicle as it moves horizontally over the ground. The model divides the vehicle into the following major elements.

(a) the sprung mass and inertia of the vehicle,

(b) the front and rear suspension system,

(c) the front and rear unsprung masses (axles, tires, etc.), and

(d) the tire compliance model.

The sprung mass can move vertically and rotate in the pitch direction while the unsprung masses are restricted to vertical motion. Linear springs and damping is used for the suspension. The tire compliance is modelled using a finite foot print method developed by Captain, et al. (22)

Figure 12 shows the schematic diagram of the vehicle model and free-body diagrams of the components.

5.3.3 Governing Equations

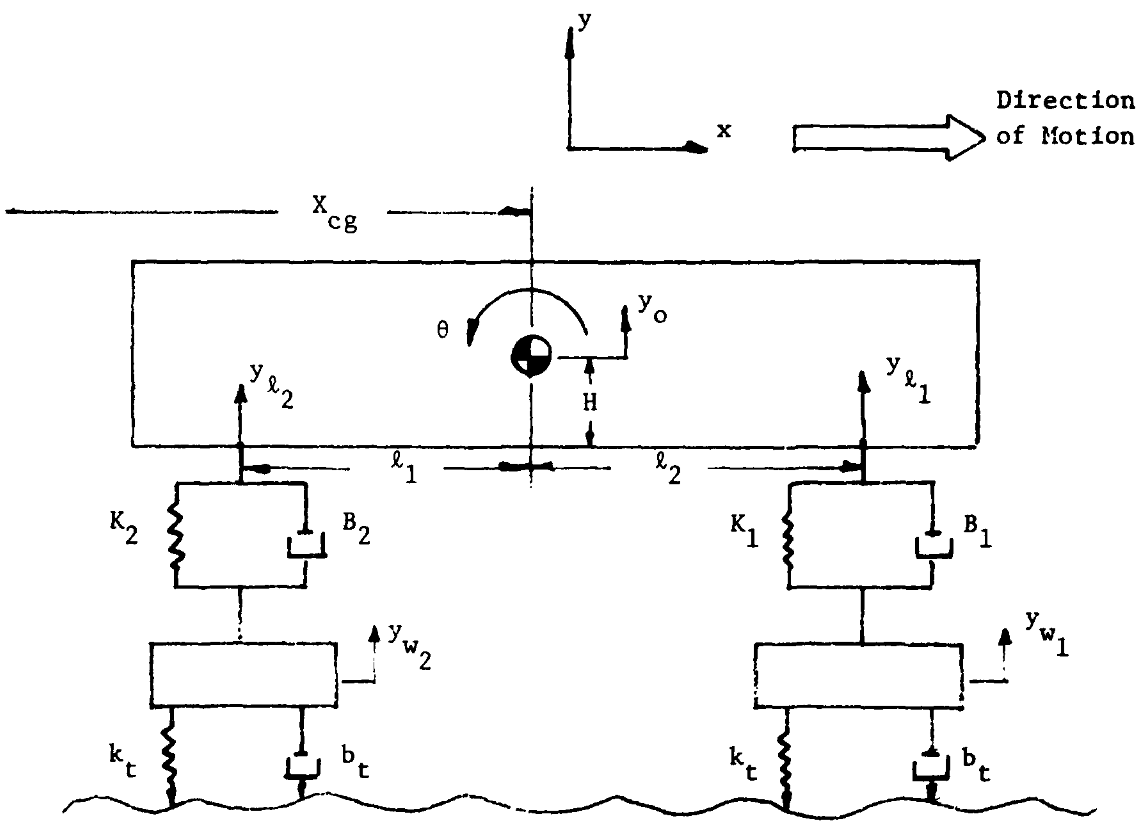
The vertical equation of motion for the sprung mass is:

$$m_v \ddot{y}_o = 2 \left(F_{y1} + F_{y2} \right) - m_v g \qquad (1)$$

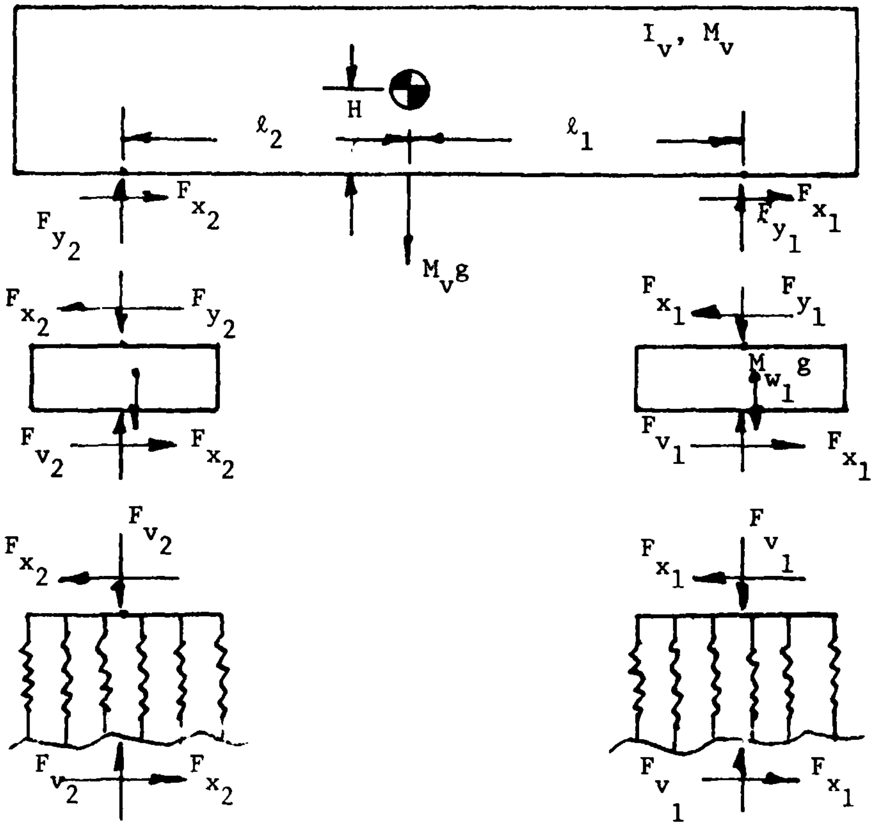
The factor of 2 is introduced because each unsprung mass shown in Figure 12 represents one-half of the axle and one tire.

The equation of motion for pitch is:

$$\begin{aligned} I_v \ddot{\theta} = 2\Big[& - F_{y2} \left(\ell_2 \cos\theta - H \sin\theta \right) \\ & + F_{x2} \left(H \cos\theta + \ell_2 \sin\theta \right) \\ & + F_{y1} \left(\ell_1 \cos\theta + H \sin\theta \right) \\ & + F_{x1} \left(-\ell_1 \sin\theta + H \cos\theta \right) \Big] \end{aligned} \qquad (2)$$


y
x
Direction of Motion
X_{cg}
θ
y_o
y_{ℓ_2}
H
y_{ℓ_1}
ℓ_1
ℓ_2
K_2
B_2
K_1
B_1
y_{w_2}
y_{w_1}
k_t
b_t
k_t
b_t

(a) Overall Model


I_v, M_v
H
ℓ_2
ℓ_1
F_{x_2}
F_{y_2}
F_{x_1}
F_{y_1}
$M_v g$
F_{x_2}
F_{y_2}
F_{x_1}
F_{y_1}
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F_{v_2}
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F_{v_2}
F_{x_2}
F_{v_1}
F_{x_1}
F_{v_2}
F_{x_2}
F_{v_1}
F_{x_1}

(b) Free Body Diagrams of the Components

FIGURE 12. DIAGRAM OF THE VEHICLE MODEL.

The displacement variables shown in Figure 12 are defined relative to the equilibrium positions of the masses with the vehicle on flat ground.

Suspension forces are given by the following relationships,

Spring Forces

$$F_{k1} = K_1\left(y_{\omega 1} - y_{\ell 1} + y_{i1}\right) \tag{3}$$

$$F_{k2} = K_2\left(y_{\omega 2} - y_{\ell 2} + y_{i2}\right) \tag{4}$$

Damping Forces

$$F_{d1} = B_1\left(\dot{y}_{\omega 1} - \dot{y}_{\ell 1}\right) \tag{5}$$

$$F_{d_2} = B_2\left(\dot{y}_{\omega 2} - \dot{y}_{\ell 2}\right) \tag{6}$$

Total Suspension Force

$$F_{y1} = F_{d1} + F_{k1} \tag{7}$$

$$F_{y1} = F_{d2} + F_{k2} \tag{8}$$

where $y_{\ell 1} = y_o + \ell_1\theta$ (9)

$y_{\ell 2} = y_o - \ell_2\theta$ (10)

and y_{i1} = initial deflection of the front suspension

y_{i2} = initial deflection of the rear suspension

Note that there are no provisions for stops or limits on the suspension, although that could be added to the model later, if desired.

The equations of motion for the two unsprung masses are,

$$M_{\omega 1}\ddot{y}_{\omega 1} = F_{v1} - F_{y1} - M_{\omega 1}g \tag{11}$$

$$M_{\omega 2}\ddot{y}_{\omega 2} = F_{v2} - F_{y2} - M_{\omega 2}g \tag{12}$$

This model assumes that the unsprung masses or axles move at a constant velocity in the horizontal direction. A more complicated model would be required to take into account any horizontal compliance and degree of freedom provided by a detailed design.

The tires are modelled using the finite footprint model of Reference (22). This model distributes the stiffness and damping of the tire over a fixed footprint length, ℓ, as shown in Figure 13.

For a segment, dx, the stiffness is

$$k_x = \frac{k\ dx}{\ell} \tag{13}$$

and the damping coefficient is,

$$b_x = \frac{b\ dx}{\ell} \tag{14}$$

The vertical spring force on the segment is

$$\delta F_{vk} = \left(y - y_{\omega} + y_{ti} \right) k_x \tag{15}$$

where y = ground elevation at x

y_{ti} = initial tire deflection

The total vertical spring force can be obtained by summing or integrating the elemental forces

$$F_{vk} = \sum_{x-\ell/2}^{x+\ell/2} \delta F_{vk} = \int_{x-\ell/2}^{x+\ell/2} \left(y - y_{\omega} + y_{ti} \right) \frac{k}{\ell}\, dx \tag{16}$$

where x is the distance from the tire center to the center of the footprint.

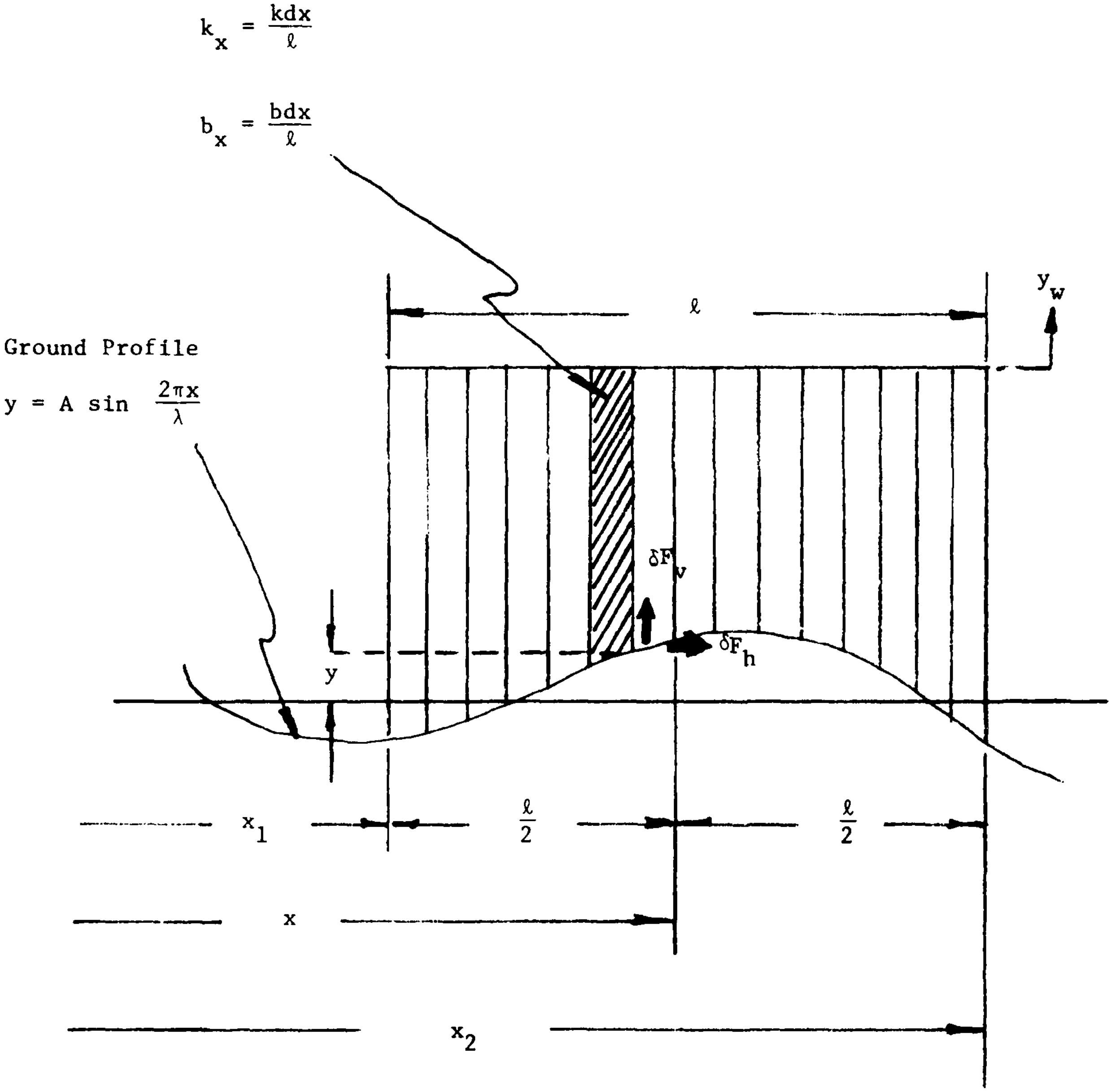

$k_x = \frac{kdx}{\ell}$
$b_x = \frac{bdx}{\ell}$
Ground Profile
$y = A \sin \frac{2\pi x}{\lambda}$
ℓ
y_w
δF_v
δF_h
y
x_1
$\frac{\ell}{2}$
$\frac{\ell}{2}$
x
x_2

FIGURE 13. THE FIXED FOOTPRINT TIRE MODEL.

Equation (16) can be integrated to give,

$$F_{vk} = k\left(\overline{y} - y_{\omega} + y_{ti}\right) \tag{17}$$

where $$\overline{y} = \int_{x-\ell/2}^{x+\ell/2} y \frac{dx}{\ell} \tag{18}$$

For purposes of this study, we are assuming that the ground can be represented as a sinusoidal wave since we do not have any better data. If detailed ground measurements on an improved road were available, more complex waveshapes or a spectral model could be used. However, for the time being,

$$y = A \sin\left(\frac{2\pi x}{\lambda}\right) \tag{19}$$

where A is the amplitude

λ is the wavelength

Substituting into Equation (18) and integrating gives,

$$\overline{y} = \frac{A\lambda}{\pi\ell} \sin\left(\frac{\pi\ell}{\lambda} \sin \frac{2\pi x}{\lambda}\right) \tag{20}$$

The damping force, F_{vb}, is given by,

$$F_{vb} = \int_{x-\ell/2}^{x+\ell/2} \left(\dot{y} - \dot{y}_{\omega}\right) \frac{b}{\ell}\, dx \tag{21}$$

and $$\dot{y} = \frac{dx}{dt} \cdot \frac{dy}{dx} = V \frac{dy}{dx} \tag{22}$$

where V = vehicle horizontal speed.

Combining Equations (21) and (22) gives,

$$F_{vb} = \frac{Vb}{\ell}\left(y_{x2} - y_{x1}\right) - \dot{y}_{\omega} b \tag{23}$$

where $x_2 = x + \ell/2$

$x_1 = x - \ell/2$

Substituting y from Equation (19) and manipulating allows expressing F_{vb} in the form,

$$F_{vb} = b\left(\dot{\bar{y}} - \dot{y}_{\omega}\right) \tag{24}$$

where

$$\dot{\bar{y}} = \frac{2A}{\ell} V \sin \frac{\pi\ell}{\lambda} \cos \frac{2\pi x}{\lambda} \tag{25}$$

and the total vertical tire force can be expressed as,

$$F_v = F_{vk} + F_{vb} \tag{26}$$

The horizontal tire force can be calculated by assuming that the force at the tire/ground interface is normal to the ground. The horizontal force on each element is then,

$$\delta F_x = -\frac{dy}{dx} \cdot \delta F_v \tag{27}$$

Substituting the elemental spring and damping forces from the preceding derivation and performing a series of complex algebraic manipulations and *integration in the x-direction* allows the derivation of the horizontal tire force,

$$F_x = \left(\dot{y}_{\omega}\frac{b}{\ell} + y_{\omega}\frac{k}{\ell} - y_{ti}\frac{k}{\ell}\right)\left(y_2 - y_1\right) - \frac{k}{2\ell}\left(y_2^2 - y_1^2\right)$$

$$- V\frac{b}{\ell}\,\frac{\pi}{\lambda}\left(y_2\sqrt{A^2 - y_2^2} - y_1\sqrt{A^2 - y_1^2} + \frac{2A^2\pi\ell}{\lambda}\right) \tag{28}$$

where

$$y_1 = A \sin\left[2\pi\left(x - \ell/_2\right)/\lambda\right] \tag{29}$$

$$y_2 = A \sin\left[2\pi\left(x + \ell/_2\right)/\lambda\right] \tag{30}$$

The distribution of tire force over the finite length footprint and the provision for both vertical and horizontal components is of importance for the general case where road surface wavelength can be small in comparison with tire dimensions.

5.3.4 Solution of the Equations

The equations derived in the preceding section were programmed for solution on an IBM personal computer. The program used to accomplish this is included as Appendix A of this report.

The simulation was programmed as an initial value problem. The distance x (x_1 for front and x_2 for rear) for the mid-point of the tires is computed from the initial positions plus speed multiplied by time. Vertical and horizontal tire forces for the front and rear tires, respectively, are termed F_{v1} and F_{x1}, and F_{v2} and F_{x2}.

Nonlinear tire conditions that can occur during operation are:

(a) wheel hop

(b) tire bottoming or stop

Wheel hop is taken into account by programming the following condition,

$$\left.\begin{array}{l} \text{if} \quad F_v < 0 \\ \text{then} \quad F_v = 0 \text{ and } F_x = 0 \end{array}\right\} \qquad (31)$$

Tire bottoming is programmed by providing an abrupt stiffness increase if the deflection of the tire exceeds a preset limit. That is,

$$\text{if} \left(\bar{y} - y_\omega + y_{ti}\right) > y_{\ell im}$$

$$\left.\begin{array}{l} \text{then} \quad F_v = F_v + F_{ex} \\ \phantom{\text{then}} \quad F_x = F_x + F_{ex}\left(\dfrac{y_1 - y_2}{\ell}\right) \end{array}\right\} \qquad (32)$$

$$\text{where} \quad F_{ex} = K\left(\bar{y} - y_\omega + y_{ti} - y_{\ell im}\right)\left(Td{-}1\right) \qquad (33)$$

and T_d = stiffness multiplier

The computer simulation program was formulated to allow the user to select an infinite stiffness for the suspension system. In this case, the program alters the governing equations to represent the situation where the axles and wheels are rigidly attached to the "sprung" mass or frame.

The initial conditions for each simulation are set by the following relationships:

$$y_{i1} = \frac{M_v g}{k_1} \; \frac{\ell_2}{2\left(\ell_1+\ell_2\right)} \qquad (34)$$

$$y_{i2} = \frac{M_v g}{k_2} \; \frac{\ell_1}{2\left(\ell_1+\ell_2\right)} \qquad (35)$$

$$y_{ti1} = \left(y_{i1}k_1 + M_{\omega 1}g\right) /k \qquad (36)$$

$$y_{ti2} = \left(y_{i2}k_2 + M_{\omega 2}g\right) /k \qquad (37)$$

$$x_{cg} = 0 \qquad (38)$$

$$x_1 = x_{cg} + \ell_1 \qquad (39)$$

$$x_2 = x_{cg} - \ell_2 \qquad (40)$$

5.3.5 Current Vehicle Designs

In order to verify the dynamic problems expected when the current Army RTFLTs are operated at 45 mph, a series of solutions were obtained using the model described in the preceding subsections.

As noted earlier, in the absence of detailed road roughness data, it was decided to excite the vehicles with a sinusoidal road profile. This requires, of course, a choice of wavelength and amplitude for the assumed road profile. The vertical and pitch natural frequencies of the three vehicles on their tires were calculated to lie in the 3 to 5 Hz range. At 45 mph, these correspond to wavelengths in the 13 to 22 foot range which is certainly a reasonable wavelength for road variations. The amplitude is arbitrary and was chosen to be 3 inches which was felt to be reasonable as a rather mild road undulation.

The computer simulation was then used to determine the dynamic response of each vehicle. The results for the M10A are shown in Figures 14 and 15. Figure 14 shows the vertical motion of the center of mass and the pitch motion around the center of mass. It can be seen that the motion is quite violent. Vertical motions of over 1.5 meters occur along with pitch angle amplitude of about one radian or about 60 degrees. In fact, it is clear from the vertical motion that the vehicle is bounding along with only momentary impacts with the road. This is confirmed by the wheel force variations shown in Figure 15 which shows that the vehicle is flying most of the time.

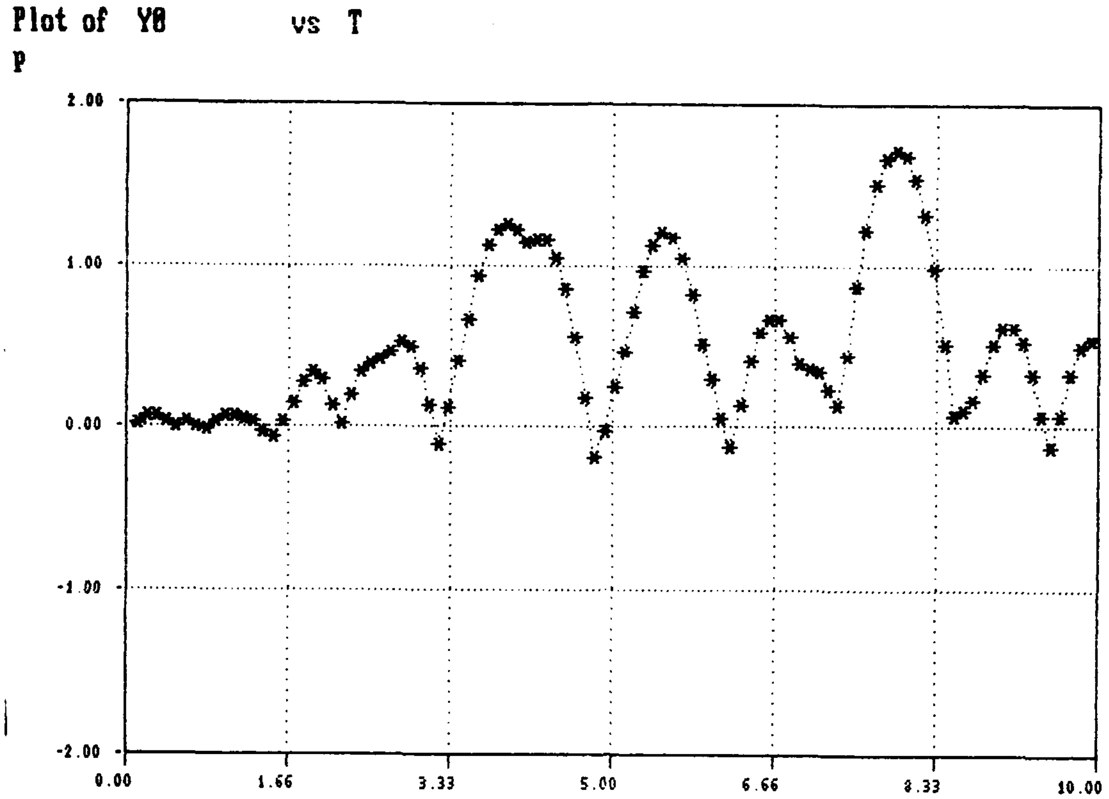
While it is dubious that this motion would occur as violently in actuality, this is a response of the present vehicle to a reasonable road profile with realistic tire stiffness and damping. Thus, it is quite clear from the solution that the vehicle would be impossible to control under these conditions.

Similar results were obtained for the other vehicles. For example, Figures 16 and 17 show the same general behavior for the Gradall 534B at 45 mph. Figures 18 and 19 show the results for the M4K.

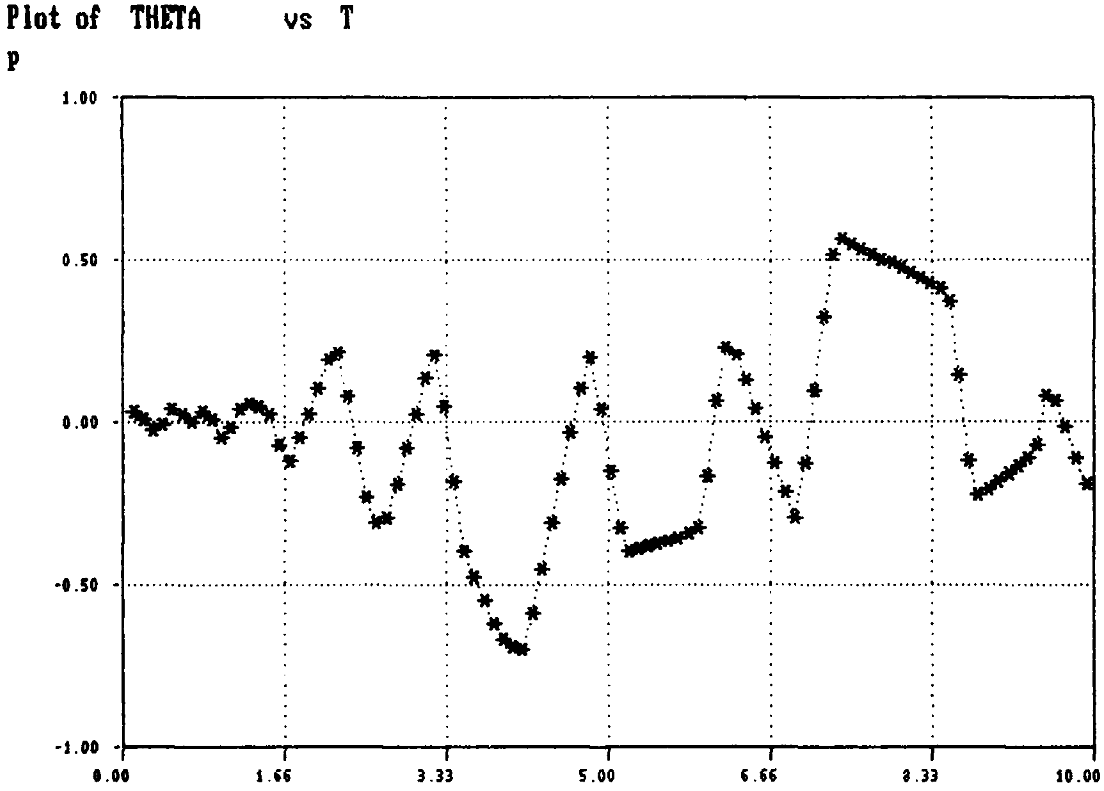
5.4 ANALYSIS OF HANDLING CHARACTERISTICS

It will be recalled that the work of Crolla concerning handling and lateral instabilities of articulated vehicles was reviewed in Section 4. That analysis showed that similar articulated vehicles exhibited both jackknifing and weaving instabilities at speeds in the range of interest. However, none of these results could be applied quantitatively to the vehicles of interest in this study.

During this study, Milliken Research Associates, experts in the field of vehicle handling and stability, were consulted on the subject of handling

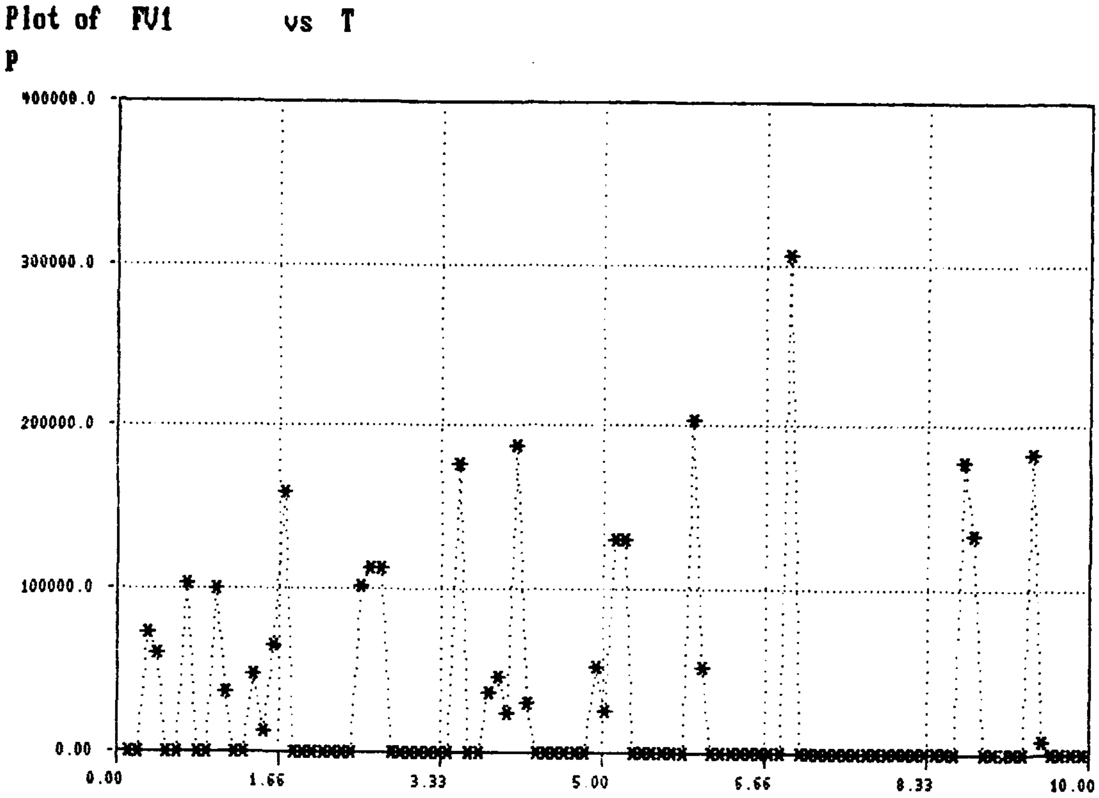


(a) Vertical Motion in Meters vs. Time

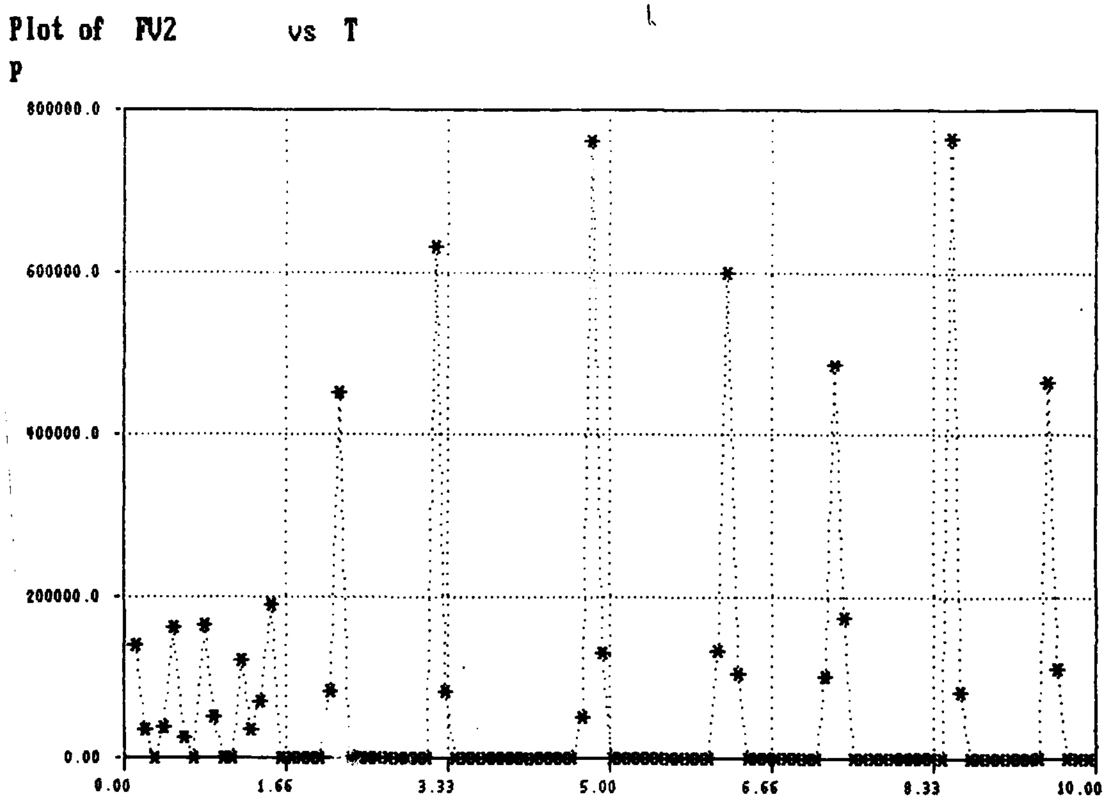


(b) Pitch Variation in Radians vs. Time

FIGURE 14. DYNAMIC SIMULATION OF THE M10A WITH NO SUSPENSION SYSTEM AT 45 MPH.

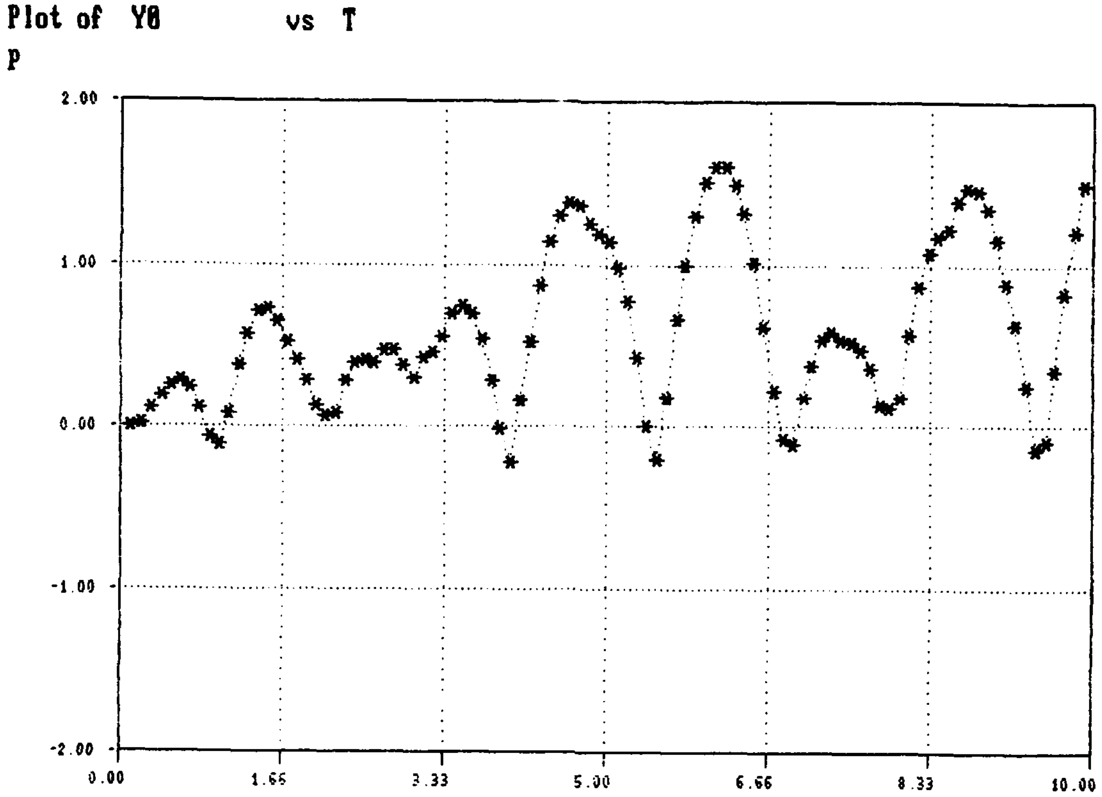


(a) Front Wheel Force

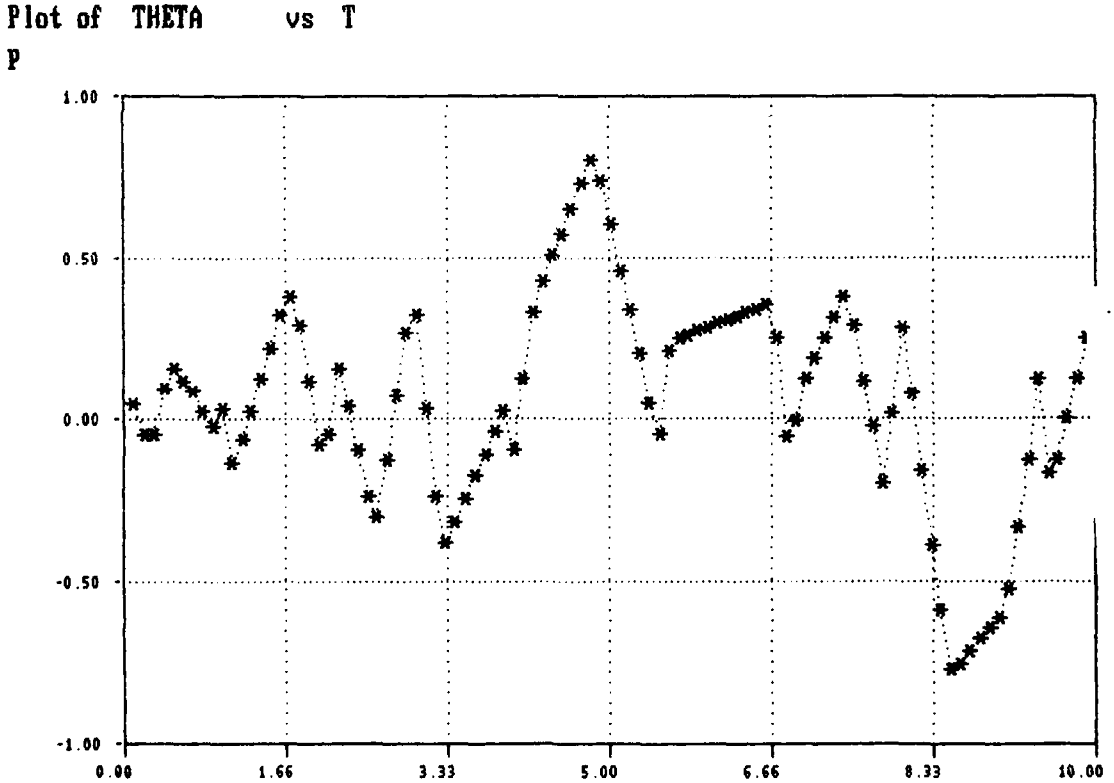


(b) Rear Wheel Force

FIGURE 15. WHEEL FORCE IN NEWTONS VS. TIME FOR THE M10A AT 45 MPH.

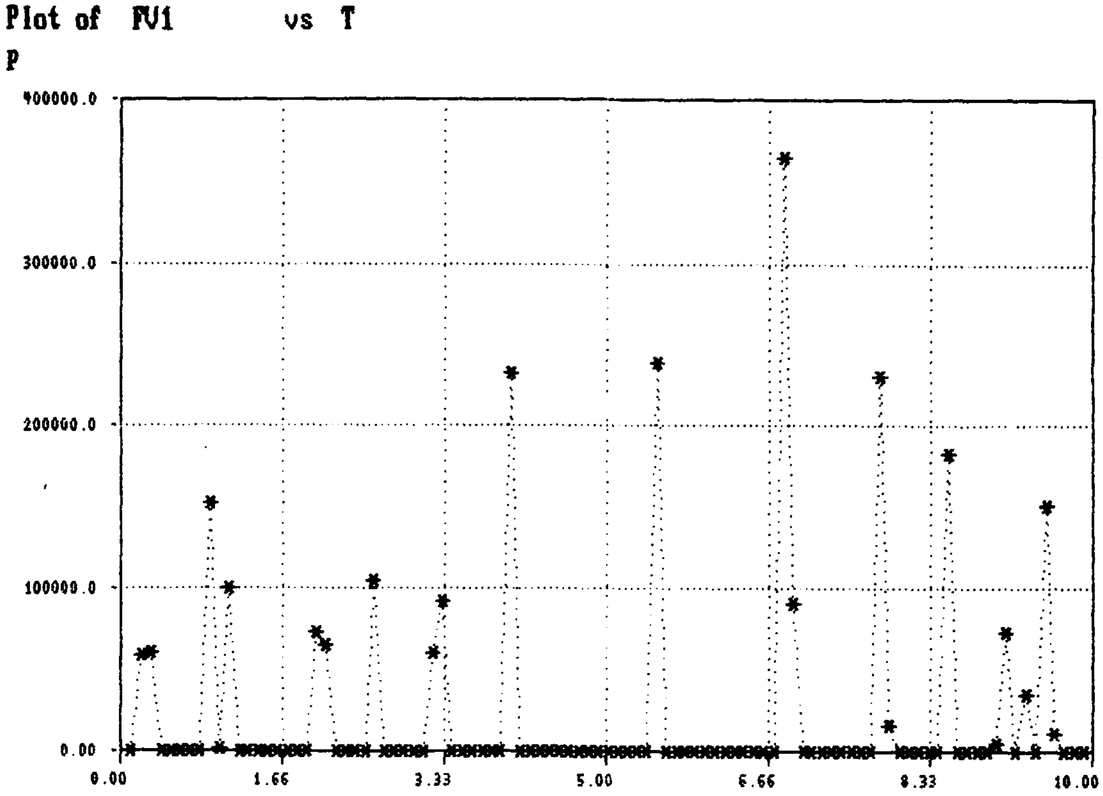


(a) Vertical Motion in Meters vs. Time

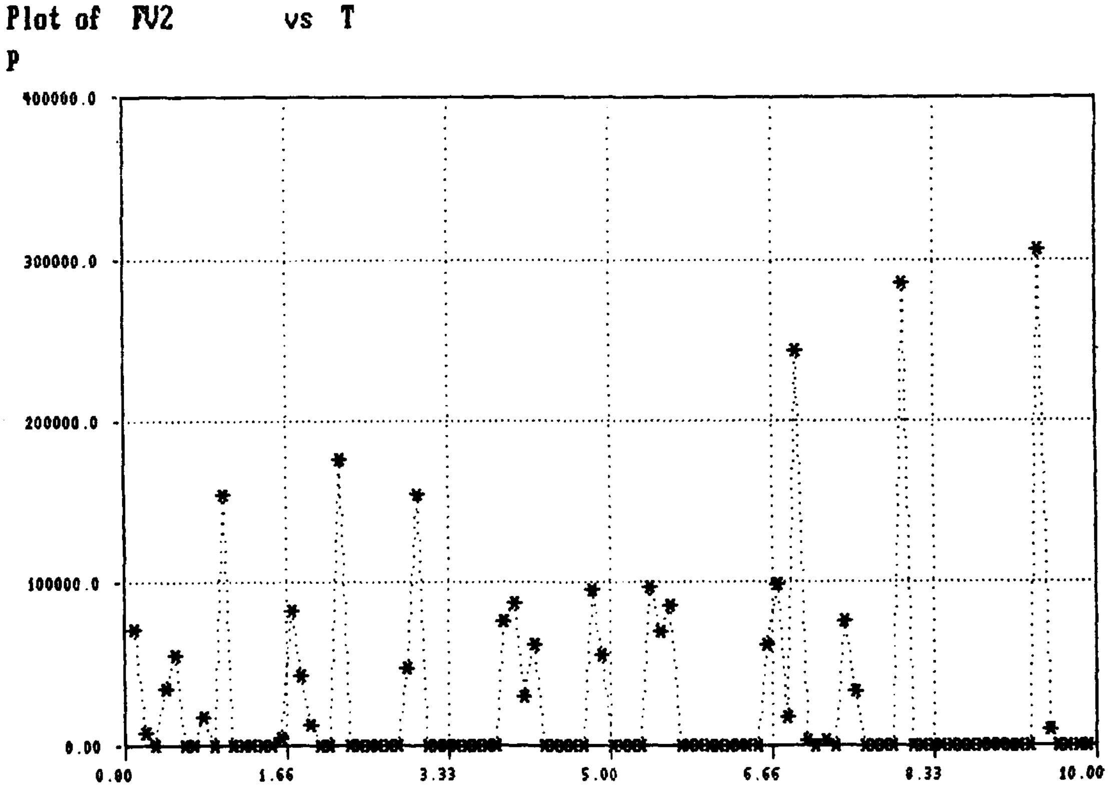


(b) Pitch Variation in Radians vs. Time

FIGURE 16. DYNAMIC SIMULATION OF THE GRADALL 534B WITH NO SUSPENSION SYSTEM AT 45 MPH.

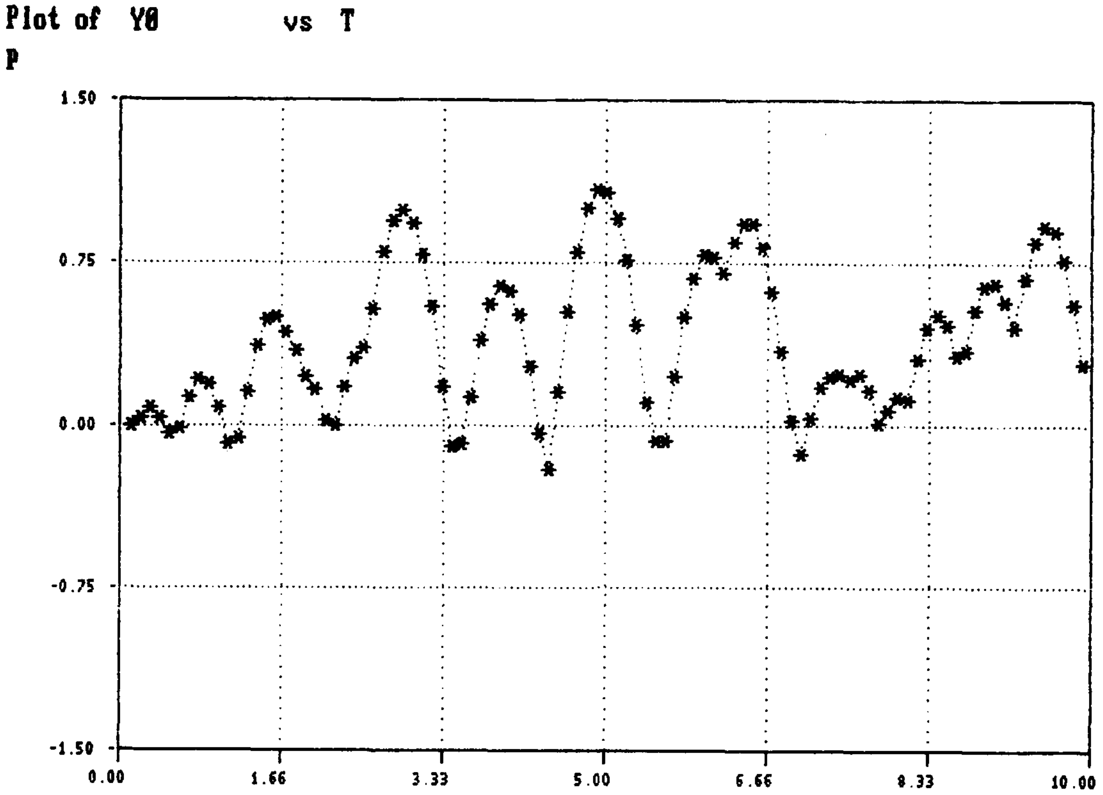


(a) Front Wheel Force

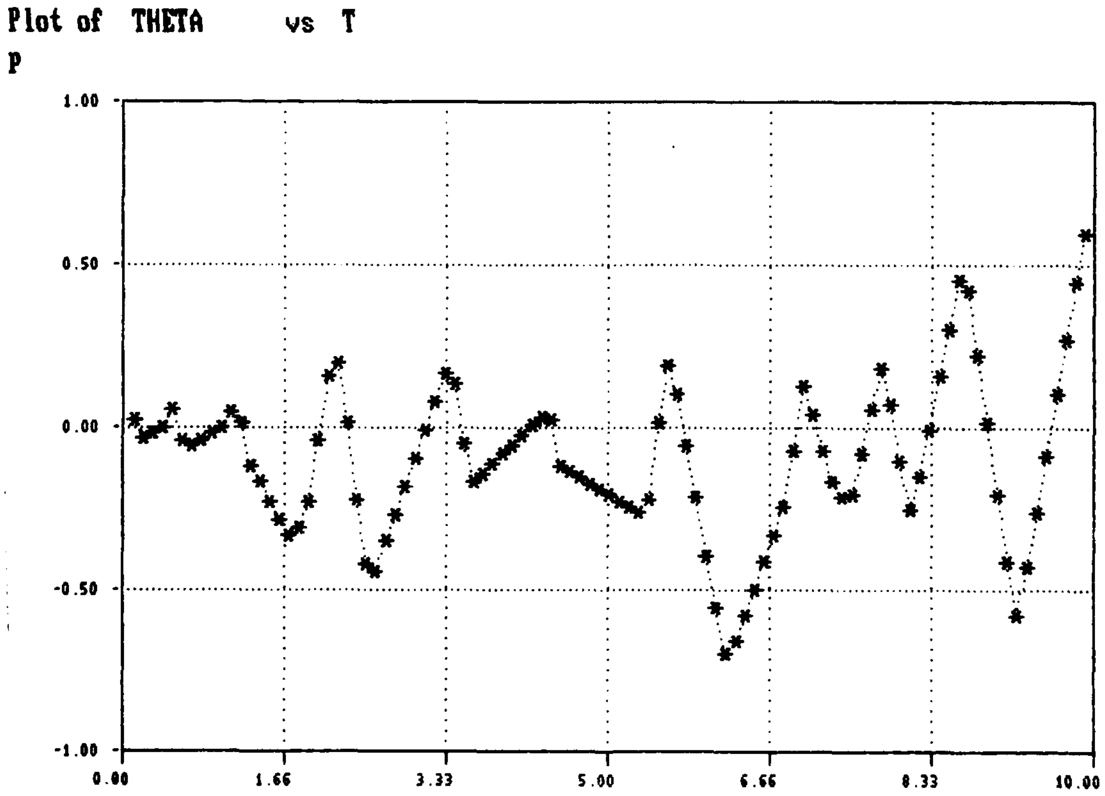


(b) Rear Wheel Force

FIGURE 17. WHEEL FORCE IN NEWTONS VS. TIME FOR THE GRADALL 534B AT 45 MPH.

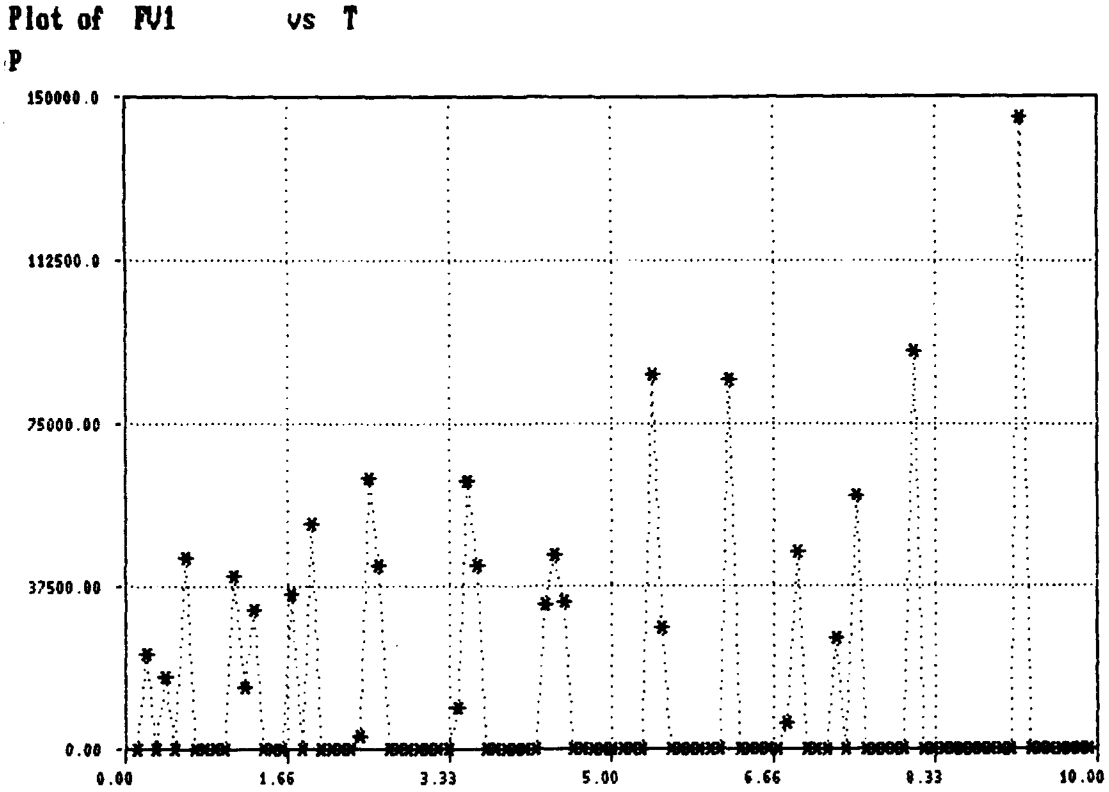


(a) Vertical Motion in Meters vs. Time

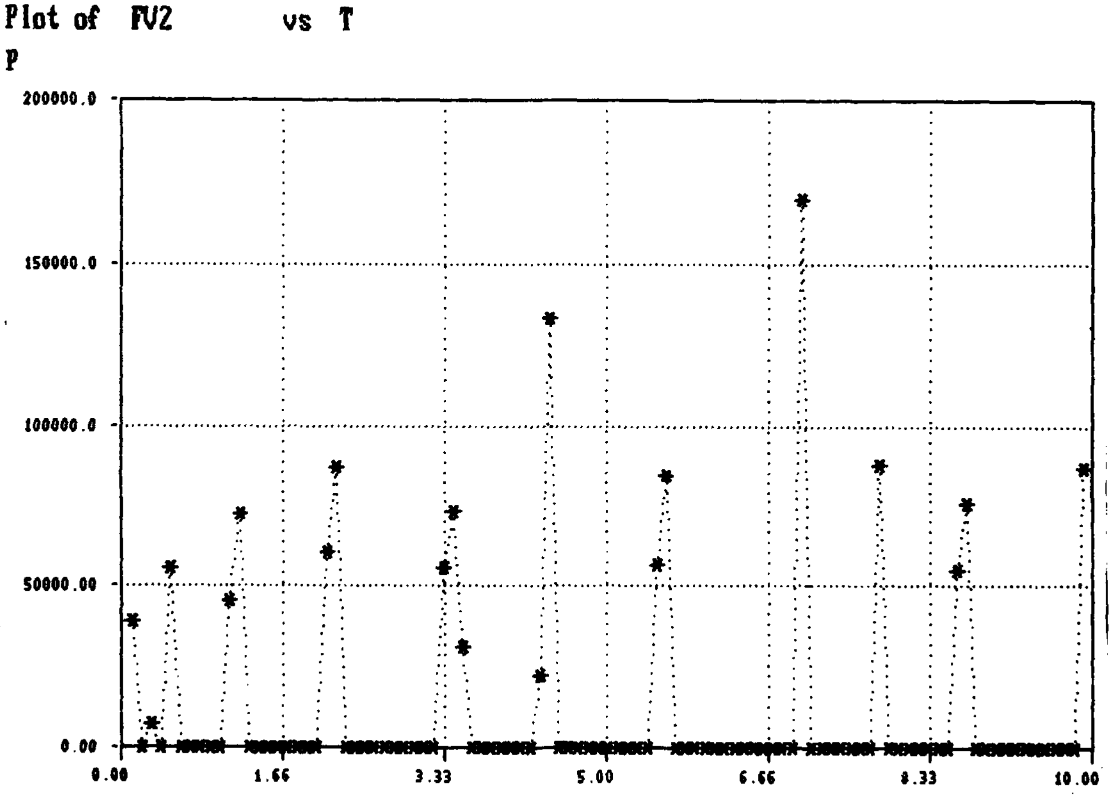


(b) Pitch Variation in Radians vs. Time

FIGURE 18. DYNAMIC SIMULATION OF THE M4K WITH NO SUSPENSION SYSTEM AT 45 MPH.



(a) Front Wheel Force



(b) Rear Wheel Force

FIGURE 19. WHEEL FORCE IN NEWTONS VS. TIME FOR THE M4K AT 45 MPH.

and steering problems. At the outset of their analysis, it was determined that it would be unlikely that the characteristics of the vehicles, steering systems and tire forces could be obtained accurately enough within the scope of this program to permit accurate prediction of steering response under realistic conditions.

Nevertheless, it was found instructive to derive the lateral equations of motion of the articulated vehicle and examine them under various simplifying assumptions. The detailed mathematical analysis is presented in Appendix B of this report and discussed in this section.

First, the dynamic equations for an articulated vehicle are derived using the Lagrange method. The degrees of freedom are:

- front section forward velocity,
- front section lateral velocity,
- front section yaw rate,
- articulation angle.

The equations are then simplified by making use of the following assumptions:

- forward velocity is constant,
- second-order small terms are negligible,
- articulation angle is small and constant or specified as a function of time.

The resulting set of linear differential equations are expressed in terms of the dependent variables

- front section yaw rate,
- front section sideslip angle.

Given enough data concerning the mass distribution of the vehicle and tire forces, these equations can be solved to simulate the dynamic response of the vehicle to small angle control inputs. However, we do not have either tire side force data nor the detailed data required to accurately predict the moments of inertia and center-of-mass locations of the individual vehicle segments.

A linear tire model was formulated to describe the tire forces in terms of the yaw rate and sideslip angle. However, this required neglecting camber and traction effects, roll steer effects, and suspension compliances. Even the remaining cornering stiffness of the tire is subject to a severe lack of available data for specific tire sizes and inflation pressures. (23)

The LaPlace transforms of the equations were taken leading to a general matrix equation in sideslip angle, β, and yaw rate, γ, with a time-varying articulation angle as the driving function. The characteristic equation of the system was determined and the coefficients which would allow calculation of the natural frequencies and damping.

Stability of the system was examined by assuming that the articulation angle is constant and known and solving for the steady-state of values of β and γ. The denominator of the steady-state solution was defined as an under-oversteer parameter. When this parameter is always positive, the vehicle is defined to be understeer. When it can be negative, the vehicle is oversteer. The parameter can also show a critical speed at which the steady-state solution diverges and the vehicle would tend to become exponentially unstable. Although a vehicle in actual practice might still be controllable by a driver, it would tend to wander and have poor handling characteristics beyond this critical speed.

The equations and the under-oversteer parameter were also derived for an equivalent or corresponding front-wheel steer vehicle.

Sufficient mass data and tire data were available for a very approximate numerical application of this analysis to the M4K and M10A forklift trucks. The results suggest the following conclusions:

- The articulated M4K is always understeer and shows no critical speed above which instability can be expected.

- The front-wheel steer version of the M4K shows an oversteer characteristic and a very high critical speed, i.e., of the order of 360 mph.

- The articulated M10A shows an oversteer characteristic and a critical speed of 41 mph, above which instability can be expected.

- The front-wheel steer version of the M10A also is oversteer and has virtually the same critical speed.

The results suggest that there may not be any severe handling problem with the M4K vehicle in the 45 mph range, even using the current type of articulated steering.

However, because of its rearward weight distribution, the M10A appears to be a handling problem in this speed range whether articulated or front-wheel steered. It is possible that the critical speed could be increased beyond the 45 mph range by moving the center of mass of the vehicle forward or by increasing the cornering stiffness of the front tires. The latter might be accomplished by increasing the tire pressure.

The mass distribution, of course, is difficult to alter significantly without a major redesign of the vehicle. One expedient might be to run the truck with a load on the forks in order to move the center-of-mass forward. Alteratively, counterweights could be removed from the rear and placed on the forks.

The dynamic characteristics of the steering system, of course, will critically affect the controllability of the vehicle at high speed. It has already been pointed out that the driver can often overcome the tendency of the vehicle to become unstable. The important general design characteristics are a tight, stiff articulation joint and a stiff, high-gain or high-power power steering system. Generally, the natural frequency of the steering system should be 5 to 10 times that of the basic vehicle response.

The proper analytical design approach would be to couple the equations describing the dynamic response of the vehicle with those describing the steering system. A first step was taken in this direction during this study by replacing the known articulation angle by a moment which is a function of articulation angle and angular velocity. The result, which will not be described here, is a set of four linear differential equations that yield a third order system. The derivation of Crolla, covered in Reference (18), covers this type of analytical model. Solution of this system is a straightforward procedure, but meaningful results would depend upon the detailed design of the hydraulic servomechanism used for steering as well as the vehicle weight and inertia characteristics, and accurate tire cornering characteristics. None of this is available at this point and much of it implies considerable experimental work to complement the analysis.

6. REQUIRED COMPONENT PERFORMANCE - PHASE II

6.1 GENERAL DISCUSSION

The potential problem areas impeding the operation of current Army RTFLTs at 45 mph were identified in Section 5.1. These are:

- Violent vertical and pitch oscillations will occur for road excitation frequencies near the natural frequencies of the vehicle. This excitation will be the expected normal condition for high-speed operation.
- Potential handling instabilities and resulting difficulty in directional control.
- Difficulty in assembling a suitable drivetrain made up of available components which will provide both low-speed gradeability and high-speed operation.
- Difficulty in obtaining suitable off-road tires which can also be operated for reasonable periods at 45 mph.

Consideration of the tire problem was deferred to Phase III since it is simply a question of commercial availability.

However, each of the other three problem areas involve design questions and the potential or necessity to add or modify components on the vehicles. Thus, they are analyzed further in this section of the report to determine a suitable design approach and, where possible, identify the required component performance.

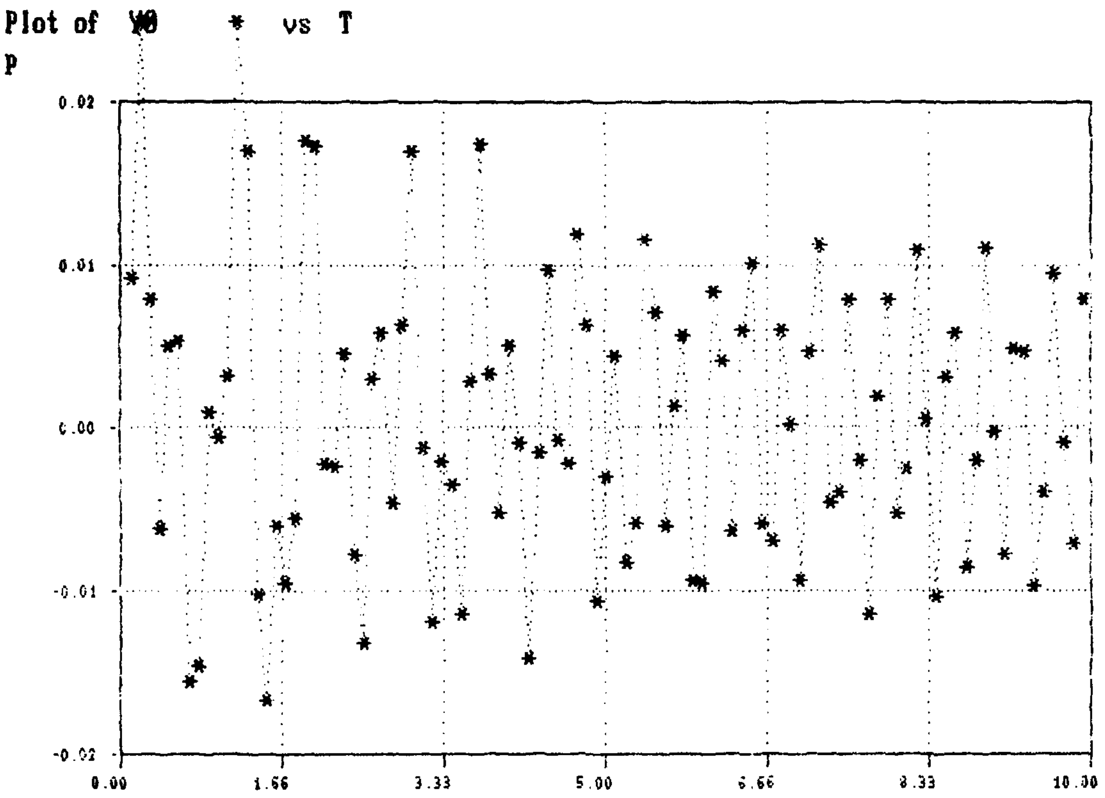
6.2 SUSPENSION SYSTEM

6.2.1 Dynamic Simulation

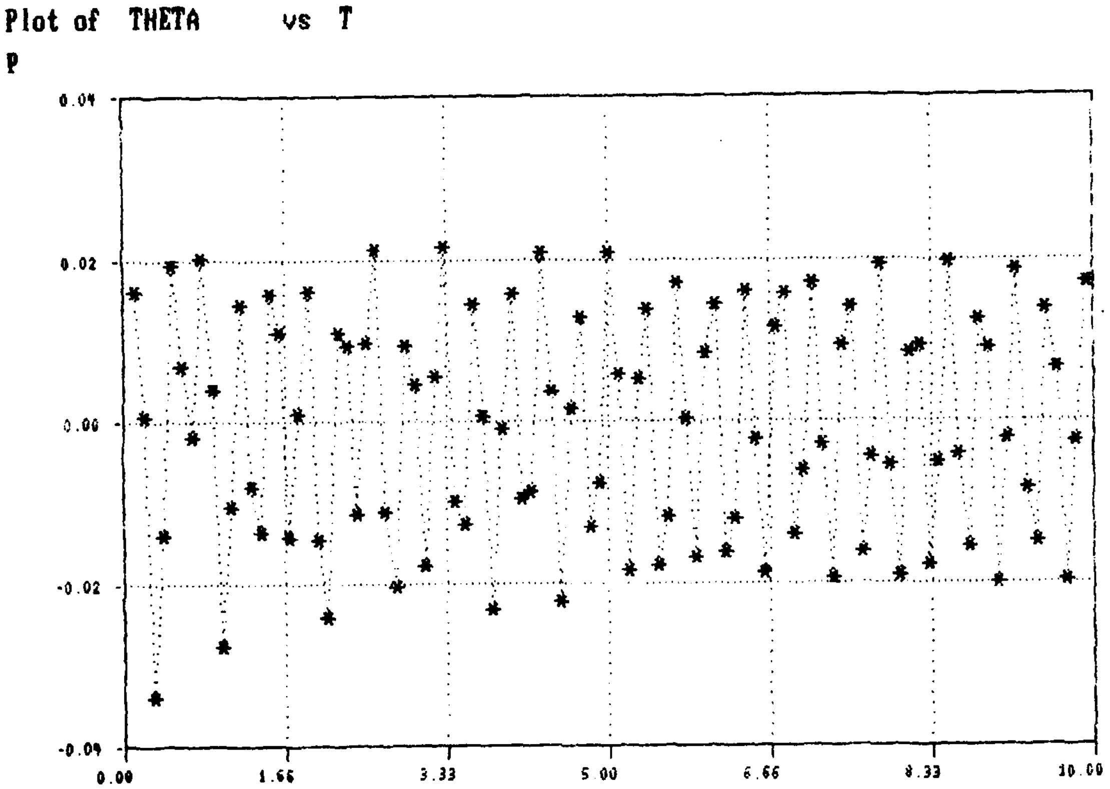
The work of Crolla (19, 20) suggested that the violent vertical oscillations would decrease markedly with the addition of a suspension system to isolate the wheels or the wheels and axles from the bulk of the vehicle mass. This, of course, changes the response mode of the vehicle to road input. The axle can respond to the road variations through deflection of the suspension while the center of mass of the vehicle remains comparatively stable.

To test this conclusion on the vehicles of interest in this study, a series of computer runs was made with the computer program listed in Appendix A and discussed in Section 5. A suspension system consisting of springs and a light damping means was inserted between each axle and the frame of the machines. The spring rate was then varied in a meaningful physical range in order to determine an "optimum" spring rate for the suspension system. This spring rate was defined as the point where the wheel forces would remain positive under the road accelerations used for the runs shown in Section 5.

The results for the M10A are shown in Figures 20 and 21. In Figure 20, it can be seen that the vertical amplitude of the center of mass is reduced, in comparison with that of Figure 14, by a factor of the order of 100. Likewise, the pitch amplitude is reduced by a factor of about 25. The vertical acceleration of the center of mass in Figure 20(a) corresponds to about 0.67g. This is still significant in terms of ride quality and could undoubtedly be further optimized through the selection of spring rate and damping characteristics. However, this should be accomplished by means of an extensive design study across the expected range of excitation frequencies. It can be seen from Figure 21 that the wheels remain ;in contact with the road at all times. The suspension spring rate for this run is 443,475 Newtons/meter for a single wheel and one half axle.



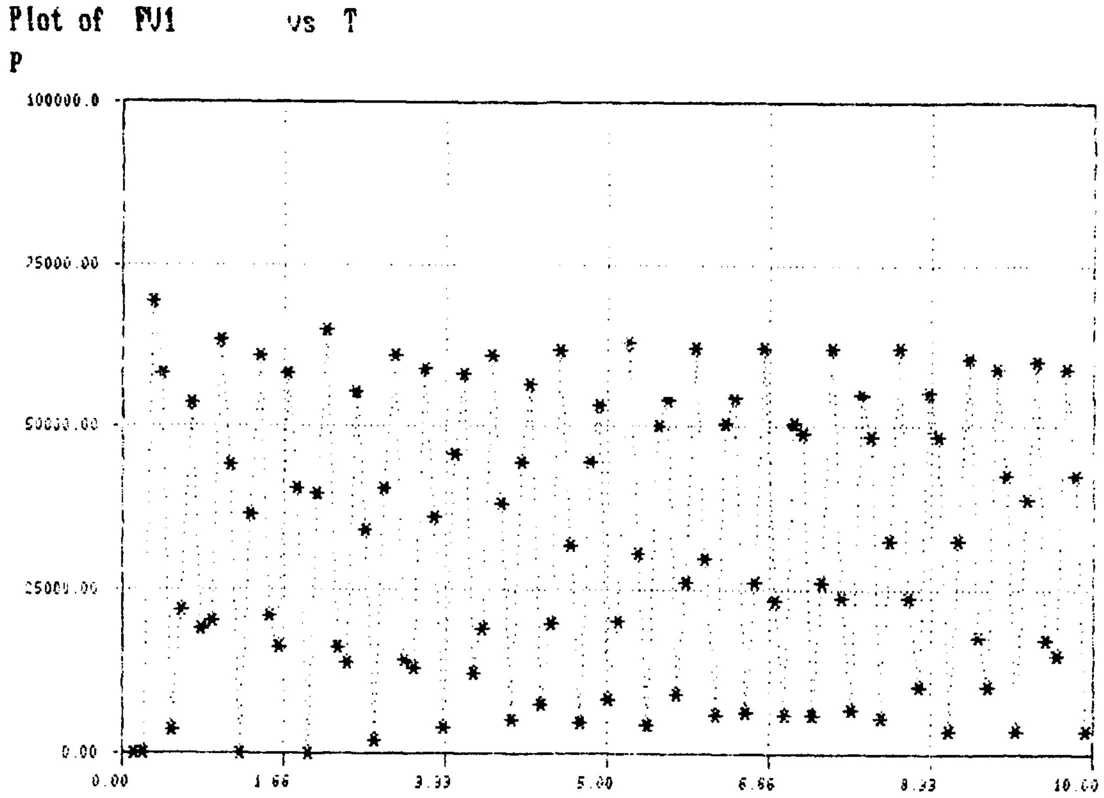
(a) Vertical Motion in Meters vs. Time



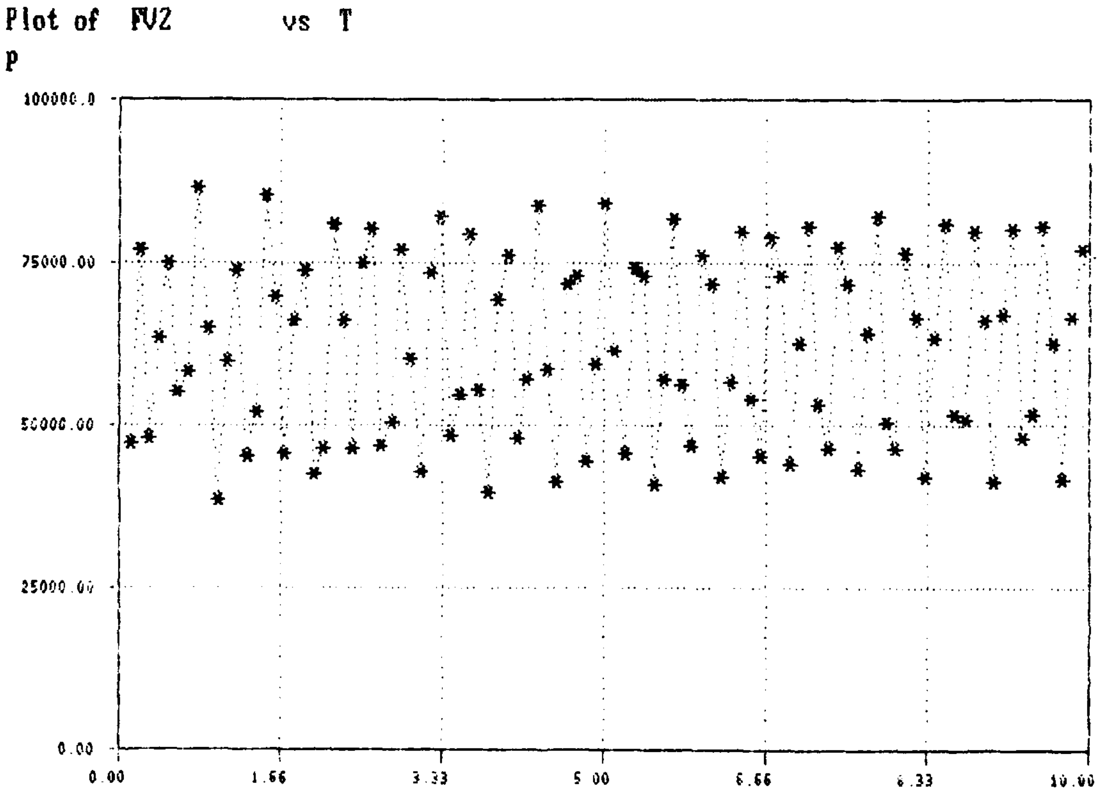
(b) Pitch Variation in Radians vs. Time

FIGURE 20. DYNAMIC SIMULATION OF THE M10A WITH SUSPENSION SYSTEM AT 45 MPH.

(Single Wheel Spring Rate of 443, 475 n/m)



(a) Front Wheel Force



(b) Rear Wheel Force

FIGURE 21. WHEEL FORCE IN NEWTONS VS. TIME FOR THE M10A SUSPENSION SYSTEM AT 45 MPH.

Similar results were obtained with the Gradall 534B VRRTFLT with a single wheel spring rate of 206,561 N/m. The results are shown in Figures 22 and 23 for comparison with Figures 16 and 17.

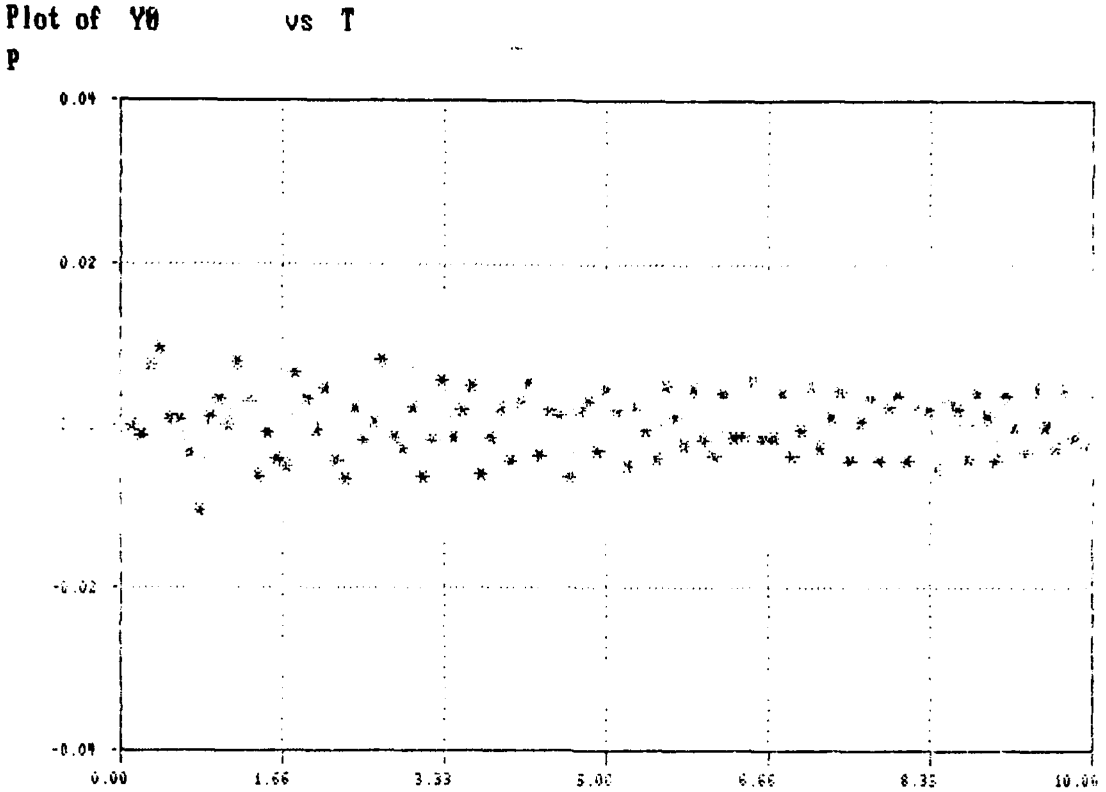
Likewise, the results for the M4K are shown in Figures 24 and 25 for comparison with Figures 18 and 19. The "optimum" single wheel spring rate for the M4K is 264,187 N/m.

6.2.2 Suspension System Design

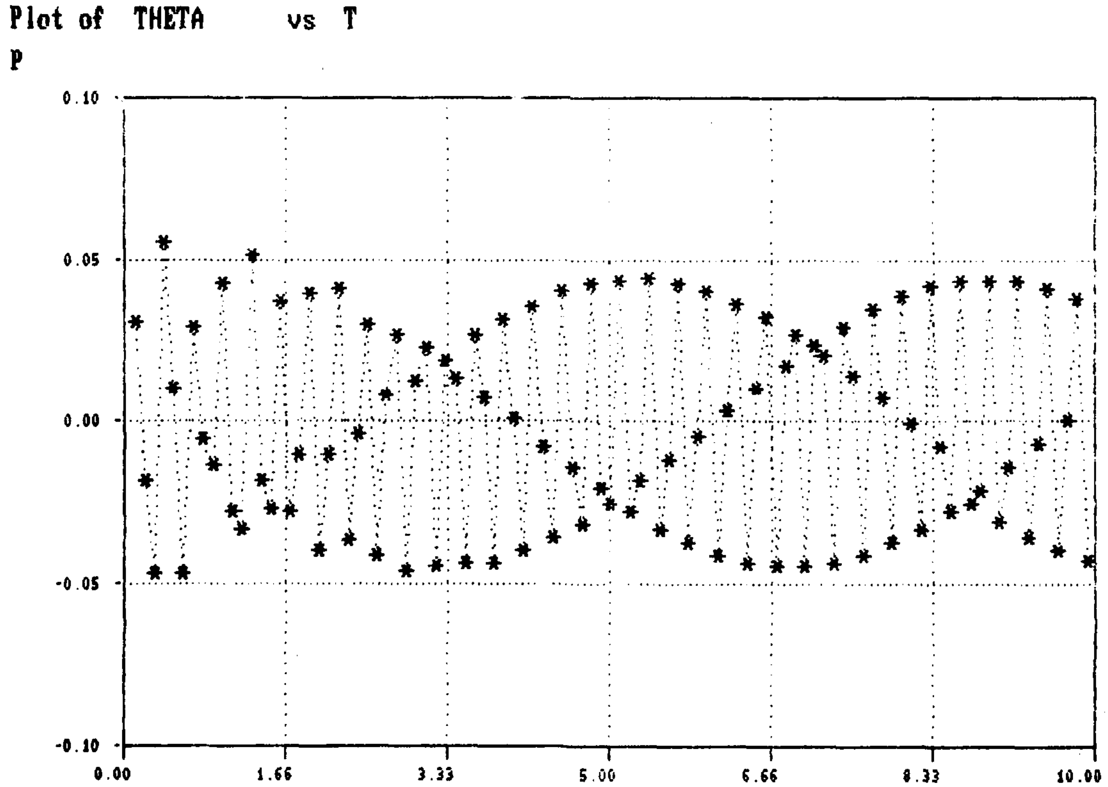
The suspension system assumed for the dynamic simulation described in the preceding section can be implemented in various ways.

For example, the axle could be mounted on a stack of leaf springs which are, in turn, mounted on the frame of the machine. This, of course, is the typical suspension design used on highway trucks. However, in this case, it is desirable to have a means for locking out the suspension system for the work made. One method that has been used with a leaf spring suspension is to employ hydraulic shock absorbers which can be valved so as to prevent relative motion between the axle and the frame.

Another general design which has been used successfully on many off-road vehicles is the hydropneumatic spring. In this case, the axle is suspended on hydraulic cylinders which are connected to an air (nitrogen) over hydraulic accumulator which supplies the compliance. The suspension can be valved off or driven against a stop to lock itself up during the work mode. Damping can be provided by a flow restriction in the hydraulic lines. This system has an inherent advantage over a leaf spring design in its flexibility of configuration. Wide ranges of force and spring rate can be obtained by adjusting the pressure and gas volume. Similar changes for the leaf spring would require significant geometry changes.



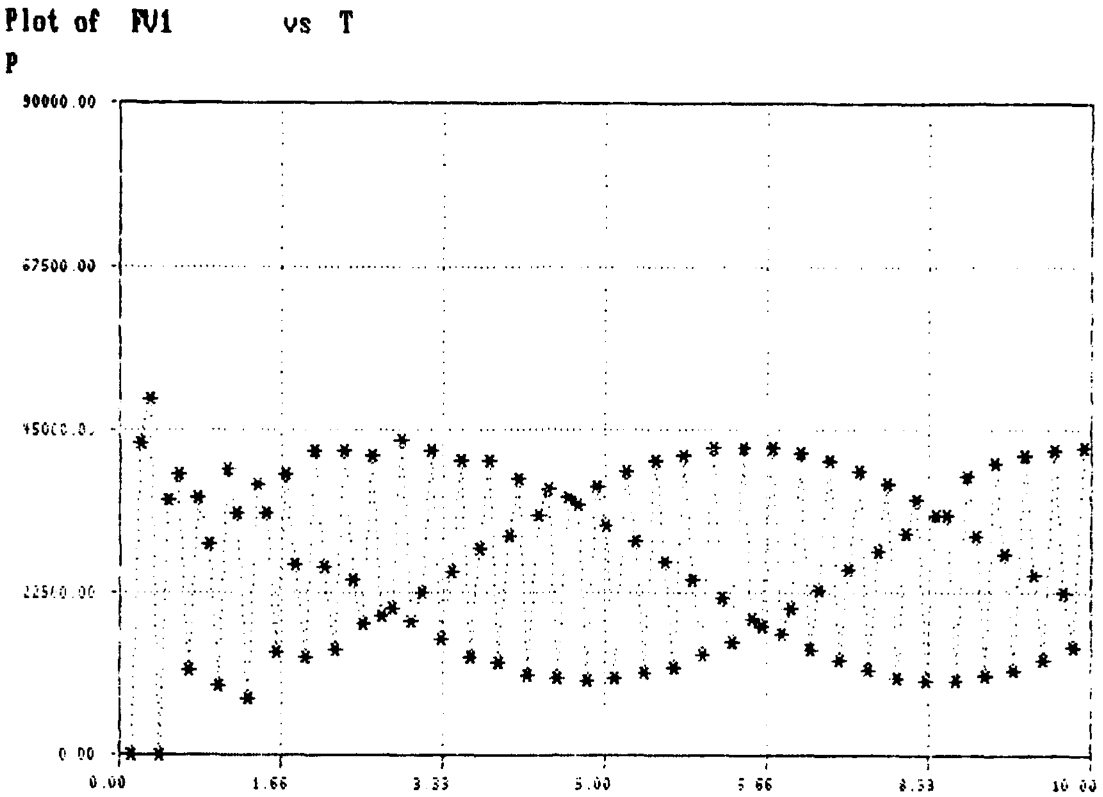
(a) Vertical Motion in Meters vs. Time.



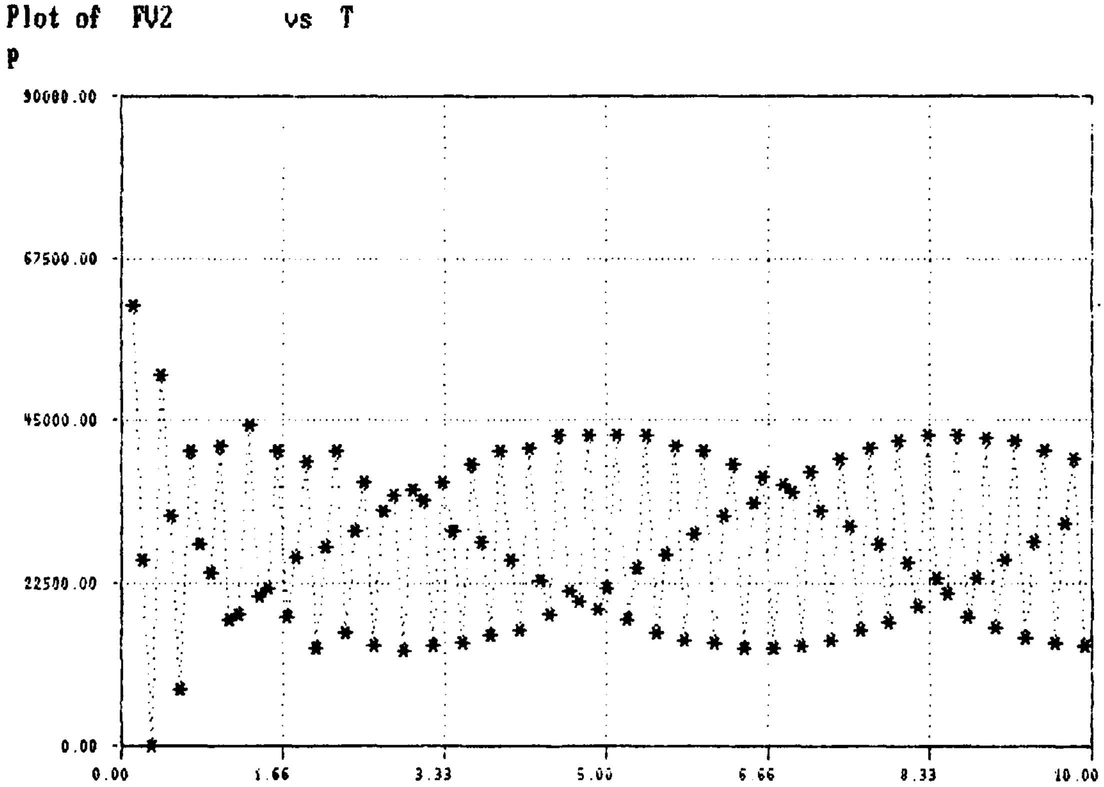
(b) Pitch Variation in Radians vs. Time

FIGURE 22. DYNAMIC SIMULATION OF THE GRADALI 534B WITH SUSPENSION SYSTEM AT 45 MPH.

(Single Wheel Spring Rate of 206, 561 N/m)

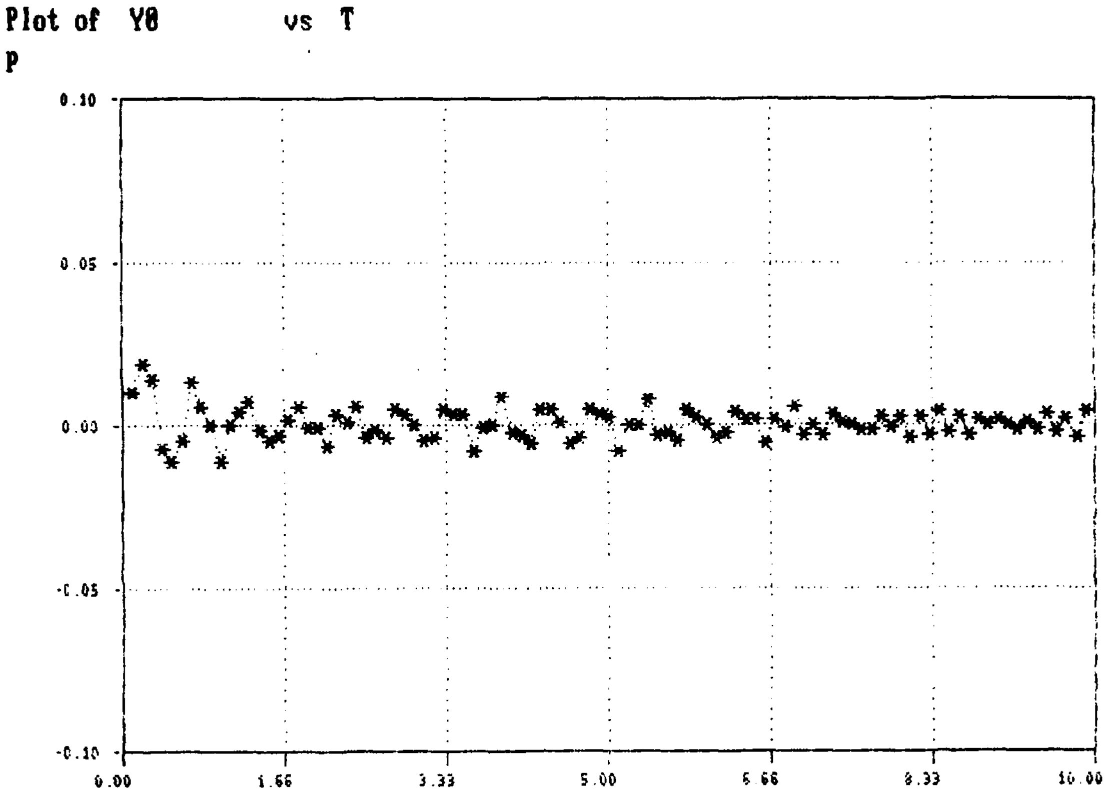


(a) Front Wheel Force

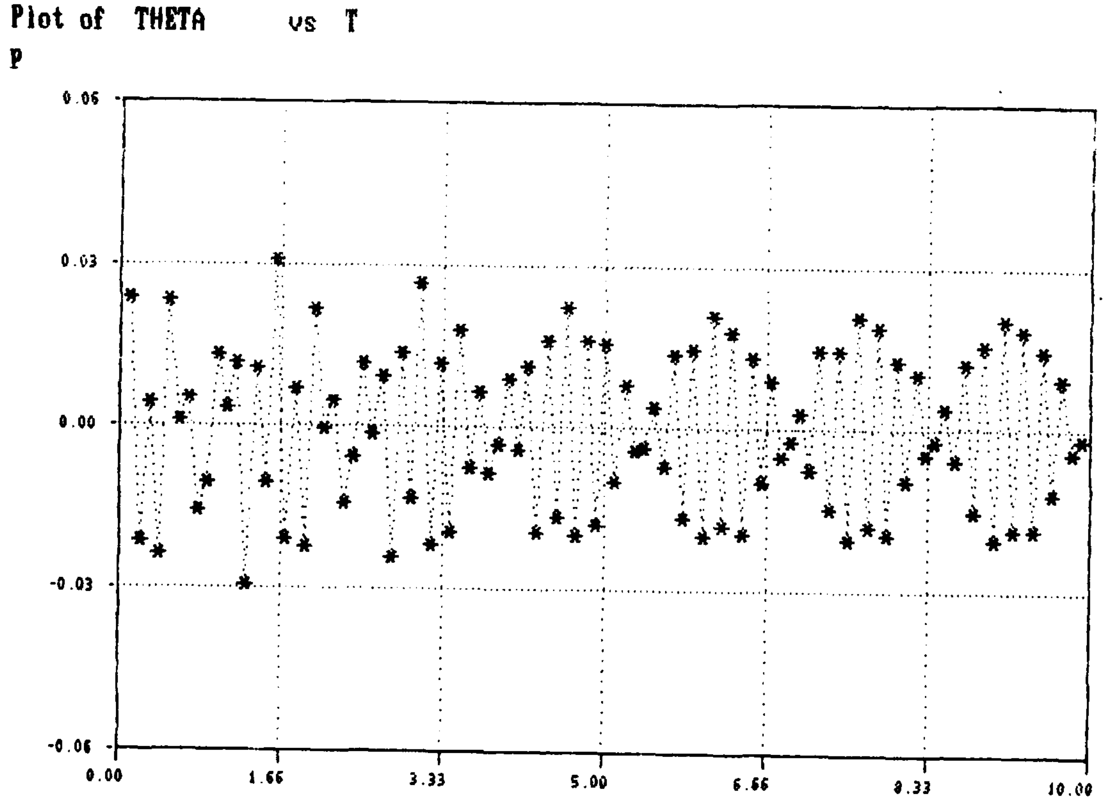


(b) Rear Wheel Force

FIGURE 23. WHEEL FORCE IN NEWTONS VS. TIME FOR THE GRADALL 534B WITH SUSPENSION SYSTEM AT 45 MPH.

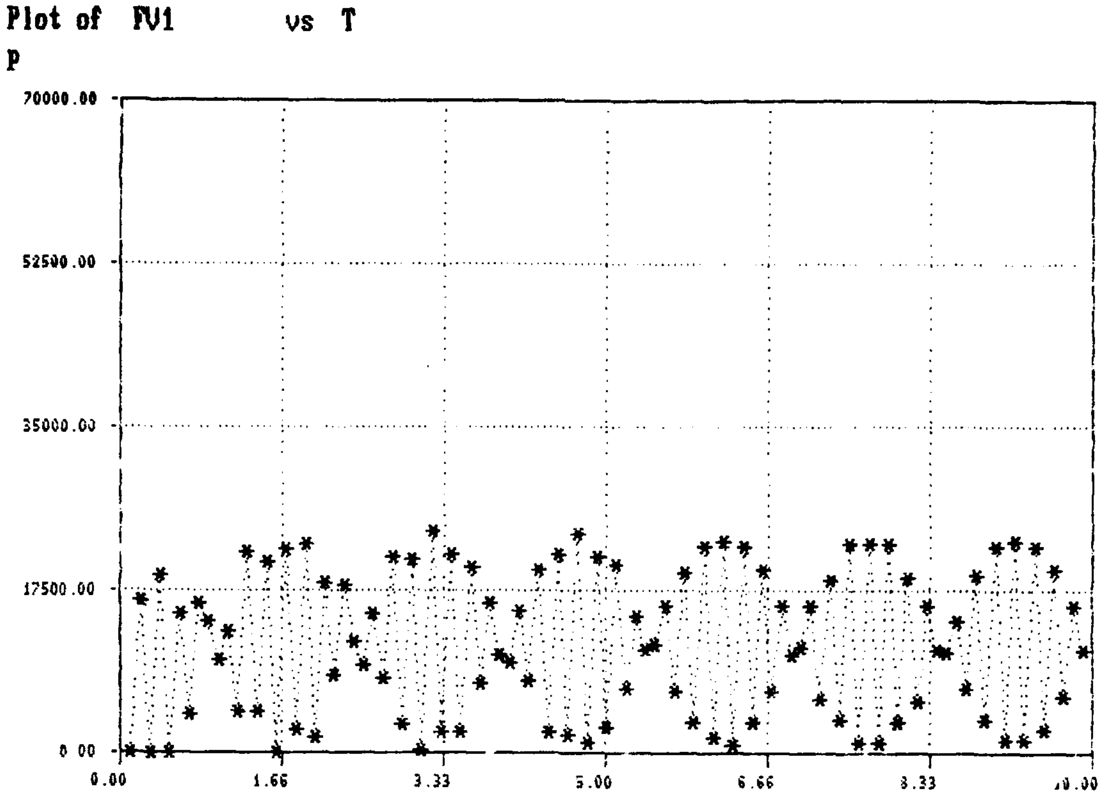


(a) Vertical Motion in Meters vs. Time

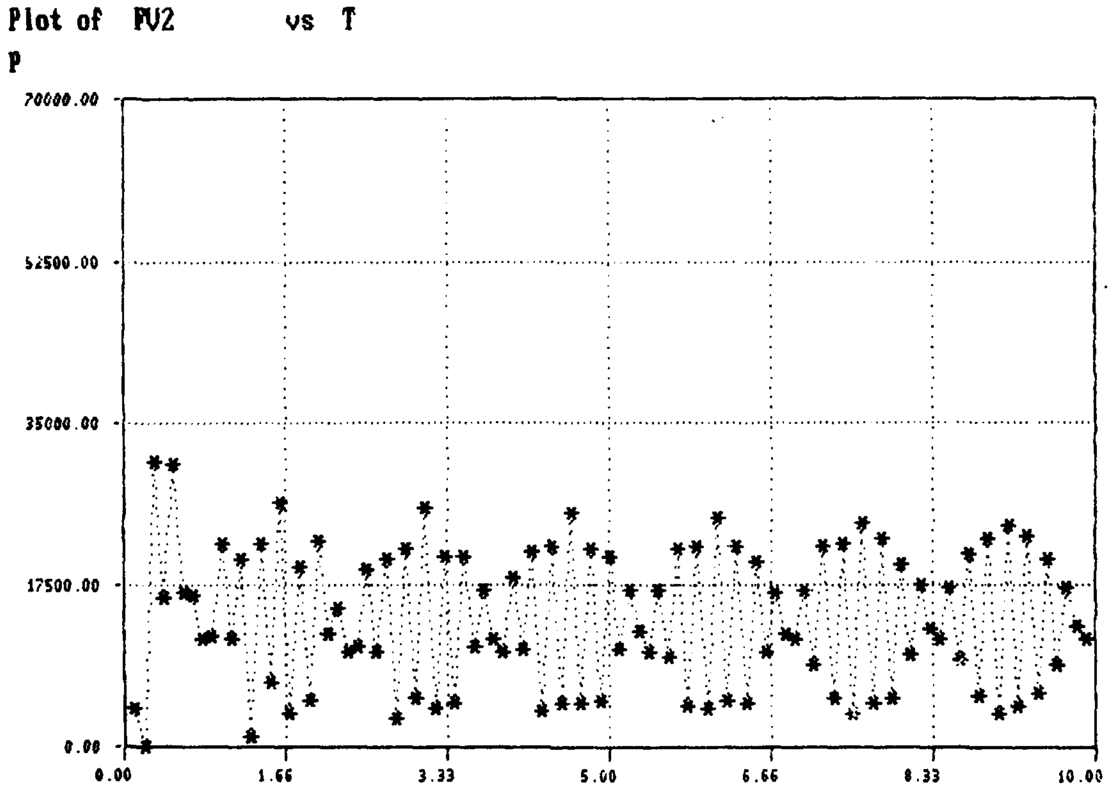


(b) Pitch Variation in Radians vs. Time

FIGURE 24. DYNAMIC SIMULATION OF THE M4K WITH SUSPENSION SYSTEM AT 45 MPH.
(Single Wheel Spring Rate of 264, 187 N/m)



(a) Front Wheel Force



(b) Rear Wheel Force

FIGURE 25. WHEEL FORCE IN NEWTONS VS. TIME FOR THE M4K WITH SUSPENSION SYSTEM AT 45 MPH.

The hydropneumatic suspension has been used for large off-road mine-haul trucks and is used on the Zettelmeyer wheel dozer and loader described in Section 3.2.1. Another example is an optional system for the John Deere Model 862 scraper which is capable of speeds up to about 30 mph. Like the Zettelmeyer system, the axle is supported by a pivoted arm which is supported on the end opposite the pivot by a hydraulic cylinder as shown in Figure 26. (24) The frame must be cut away to provide clearance for the axle motion. Presumably, mounting points for the pivot and the fixed end of the hydraulic cylinder also need to be added to the frame.

A schematic diagram of the hydraulic system is shown in Figure 27. The leveling system is a feature in addition to the dynamic suspension characteristics which allows the static height of the vehicle to be adjusted or held constant, regardless of the load. The lockdown valve, on this system, causes the hydraulic cylinders to drive the axle upward against the frame stops and hold it there rigidly.

The Caterpillar 615 scraper also offers an optional axle suspension which is similar in design and can be added to an existing vehicle.

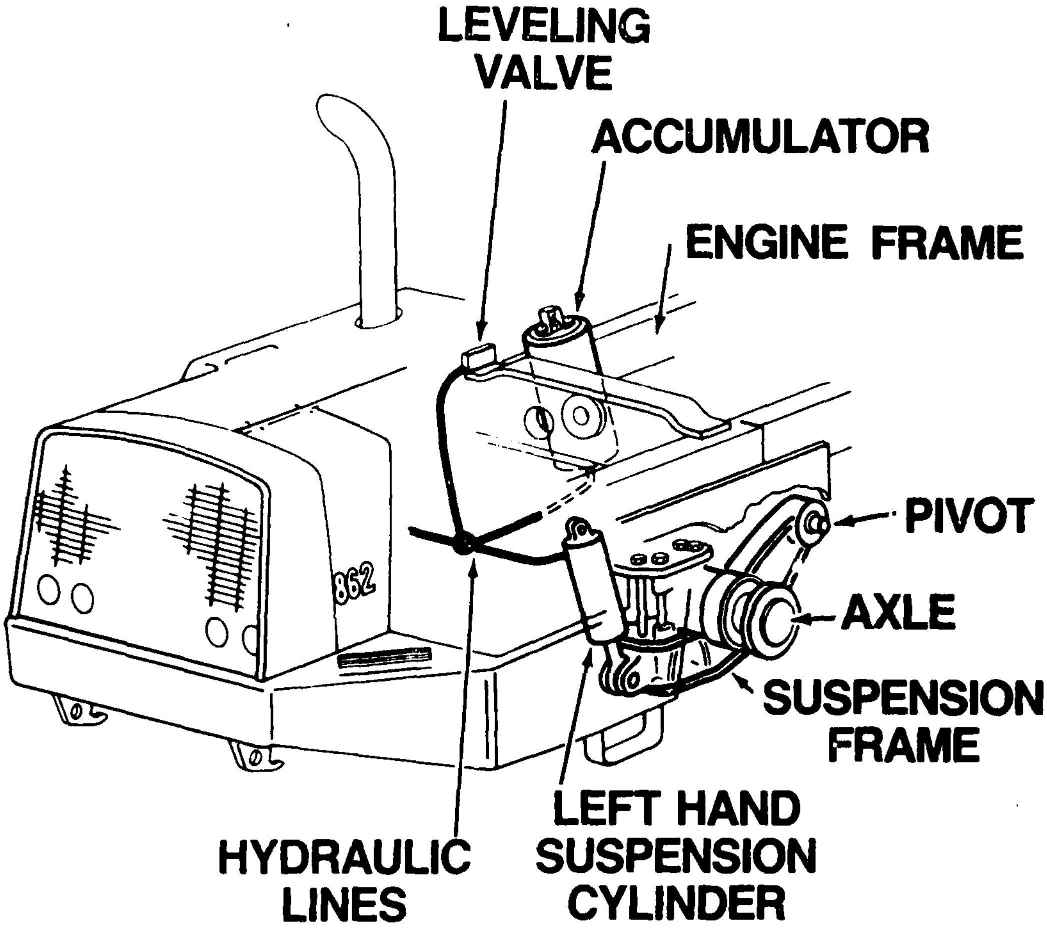
The design relationships that govern the design of the hydropneumatic suspension system are straightforward. The force which can be supported by a single hydraulic cylinder is given by,

$$F = r A p \qquad (41)$$

where A = area of the cylinder

r = geometry factor which depends upon the detailed design but might be expected to range between about 0.8 and 2.0

p = hydraulic pressure in the cylinder


LEVELING VALVE
ACCUMULATOR
ENGINE FRAME
PIVOT
AXLE
SUSPENSION FRAME
LEFT HAND SUSPENSION CYLINDER
HYDRAULIC LINES
862

Adapted from Ref.(24)

FIGURE 26. AXLE SUSPENSION SYSTEM FOR THE JOHN DEERE 862 SCRAPER

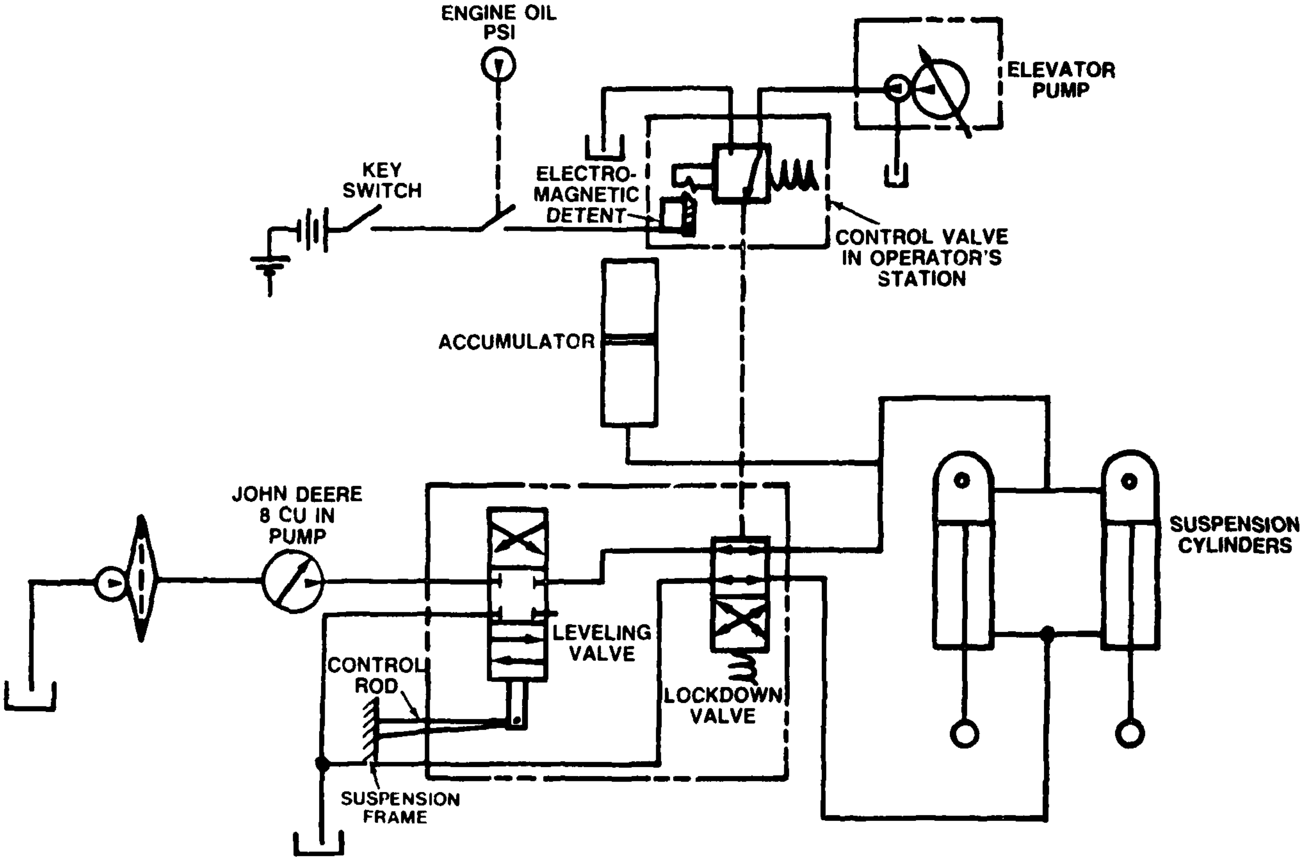

ENGINE OIL PSI
ELEVATOR PUMP
KEY SWITCH
ELECTRO-MAGNETIC DETENT
CONTROL VALVE IN OPERATOR'S STATION
ACCUMULATOR
JOHN DEERE 8 CU IN PUMP
SUSPENSION CYLINDERS
LEVELING VALVE
CONTROL ROD
LOCKDOWN VALVE
SUSPENSION FRAME

FIGURE 27. SCHEMATIC DIAGRAM OF THE HYDRAULIC CIRCUIT FOR THE JOHN DEERE 862 SCRAPER SUSPENSION SYSTEM

Assuming that $r = 1$, the volume of fluid displaced for a one inch axle travel is

$$\Delta V = A \simeq V \frac{\Delta p}{p} \qquad (42)$$

where V = the volume of gas in the hydropneumatic accumulator

The spring rate can be defined as,

$$K = \frac{\Delta F}{1} = A \, \Delta \, p \qquad (43)$$

using Eq. (41) and, substituting in Eq. (42) gives,

$$K = \frac{pA^2}{V} \qquad (44)$$

A first cut at the design of the system can be made with Eqs. (41 and (44). For example, for the M10A, the axle force, F, must be about 12,500 lbs. The pressure level in this type of system is typically limited to about 2000 psi. Substituting into Eq. (41) gives a required cylinder area, A, of 6.25 in^2. Eq. (44) then gives,

$$K = \frac{12500\ A}{V} \simeq 2532\ \frac{\text{lb.}}{\text{in.}}$$

using the results of Section 6.2.1 (443,475 N/M).

Thus, $V = 31\ \text{in.}^3$

which is a reasonable gas volume.

This preliminary calculation shows that the hydropneumatic suspension system for the M10A can be implemented by three inch diameter wheel cylinders connected to an accumulator with a 31 in^3 volume. These components are straightforward and easy to purchase or custom fabricate. Likewise, all of the additional components such as valves and lines are standard available hydraulic components.

Similar calculations can be done for the Gradall 534B and the M4K. At a quiescent pressure level of 2000 psi, the resulting wheel cylinder and gas volumes are:

Gradall 534B;	wheel cylinder - 1.75 in. diameter gas volume - 10.6 in^3
M4K;	wheel cylinder - 1.25 in. diameter gas volume - 2.07 in^3

These can, of course, be altered for design convenience simply by operating the system at a lower pressure.

Thus, it can be concluded that there should be no obstacle to obtaining suitable components with which to add a hydropneumatic suspension system to the vehicles of interest.

This is not intended, however, to minimize or downplay the effort which will be required to design the system in detail and optimize its response for a wide variety of road conditions. The design of the correct amount of flow restriction to introduce optimum damping into the system will require careful attention. Ultimately, the system must be built and tested experimentally to correctly size all components.

6.3 STEERING COMPONENTS

6.3.1 Articulated Vehicles

The analysis of Section 5.4 and Appendix B suggests that the M4K in its present configuration should be stable for small steering angles at 45 mph.

Examining the analysis and the work of Crolla (18) suggests that the stability of the M10A could be improved by moving the center of mass of the vehicle forward, especially by moving the center-of-mass of the front section forward. This is, of course, difficult to accomplish with an articulated vehicle, especially since it conflicts with the requirement for a counterbalancing weight for the fork load. The vehicle can be run on the road with a stable fork load to improve the handling characteristics. However, this increases the running weight of the machine which will increase the power required to maintain the 45 mph road speed. An alternative would be to provide counterweights that can be moved from the rear to the forks for high speed travel.

Consideration should also be given to increasing the wheelbase of the vehicle. This will increase the directional damping of the vehicle and improve static stability at higher speeds. This would, of course, require altering the specifications for the vehicles and can be expected to adversely affect the turning radius.

In any case, the subject of overall vehicle weight balance goes beyond the performance requirements of the steering components.

If, as the analysis suggests, the lateral stability becomes marginal at speeds in the range of 45 mph, careful driver control can probably extend the stable range. For the M10A, this may require improvement of the hydraulic power steering system to increase its power and response. In general, this can be accomplished by increasing the hydraulic pressure and/or the size of the steering cylinders. A pump having increased pressure or flow capacity or both would also typically be required.

Additionally, the articulation joint itself may require design improvement to eliminate any free play and stiffen the structural components.

There would not appear to be any questions of component availability to accomplish an improvement of the steering system. Hydraulic components are available in a wide range of sizes. The most difficult task is likely to be the fitting of larger components into the space available. This would require a detailed layout design and, possibly, relocation of other components that interfere with the steering.

Since it is not clear, and is not likely to be clear from analytical considerations alone, that an improvement of the steering is required, the logical approach would be an empirical one. An M10A or a similar vehicle, should be built with a suspension system and an upgraded drivetrain capable of 45 mph. This vehicle could then be tested on a test track to determine its handling characteristics and the requirements for an improved steering system.

Parenthetically, it may be noted that a prototype of the above test vehicle is nearly available in the form of the Zettelmeyer ZL75C. This vehicle requires only minor drivetrain modifications to reach 45 mph. The manufacturer has stated that a modified vehicle could be prepared in about four months, although it might not be capable of meeting the low speed 45% gradeability requirement. It would, however, be valuable for empirical investigation of the high-speed handling characteristics.

Ultimately, if testing shows that acceptable handling at 45 mph cannot be obtained with articulated steering on the 4K and 10K RTFLT's there appears to be two viable design alternatives.

- Redesign these vehicles as rigid frame, four-wheel steer vehicles in which front-wheel steering is used for high-speed operation.

- Lock out the articulation joint for high-speed operation and replace the front axle with a conventional Ackerman steering axle.

The principal component availability question for these design alternatives is the availability of steering axles with suitable drive characteristics. Four-wheel hydraulic steering controls which are selective among front-wheel, four-wheel coordinated, four-wheel crab, and rear-wheel steering are available and currently used for a variety of agricultural tractors and other equipment. Axle availability will be addressed along with the other driveline components.

6.3.2 Ackerman Steering

The specification for the 6K VRRTFLT calls for Ackerman steering. The prototype Gradall 634B for this vehicle uses a rear-wheel steering system. As noted in Section 5.1.2, this system is not expected to be acceptable at 45 mph.

One alternative would be to operate the vehicle in reverse for high speed travel, thus producing, in effect, a front-wheel Ackerman steered vehicle. This has the added benefit of a "forward" bias for the location of the center-of-mass. The disadvantage is that presumably two operator positions (or a reversible position) would be required. No major component changes would be required.

The second alternative is to go to the four wheel selective steering system discussed in the preceding section. In this case, the principal component requirement again is a steering axle with appropriate drive characteristics.

6.4 DRIVELINE COMPONENTS

For purposes of this discussion, the driveline is considered to consist of all components from the engine to the wheels. The principal components are:

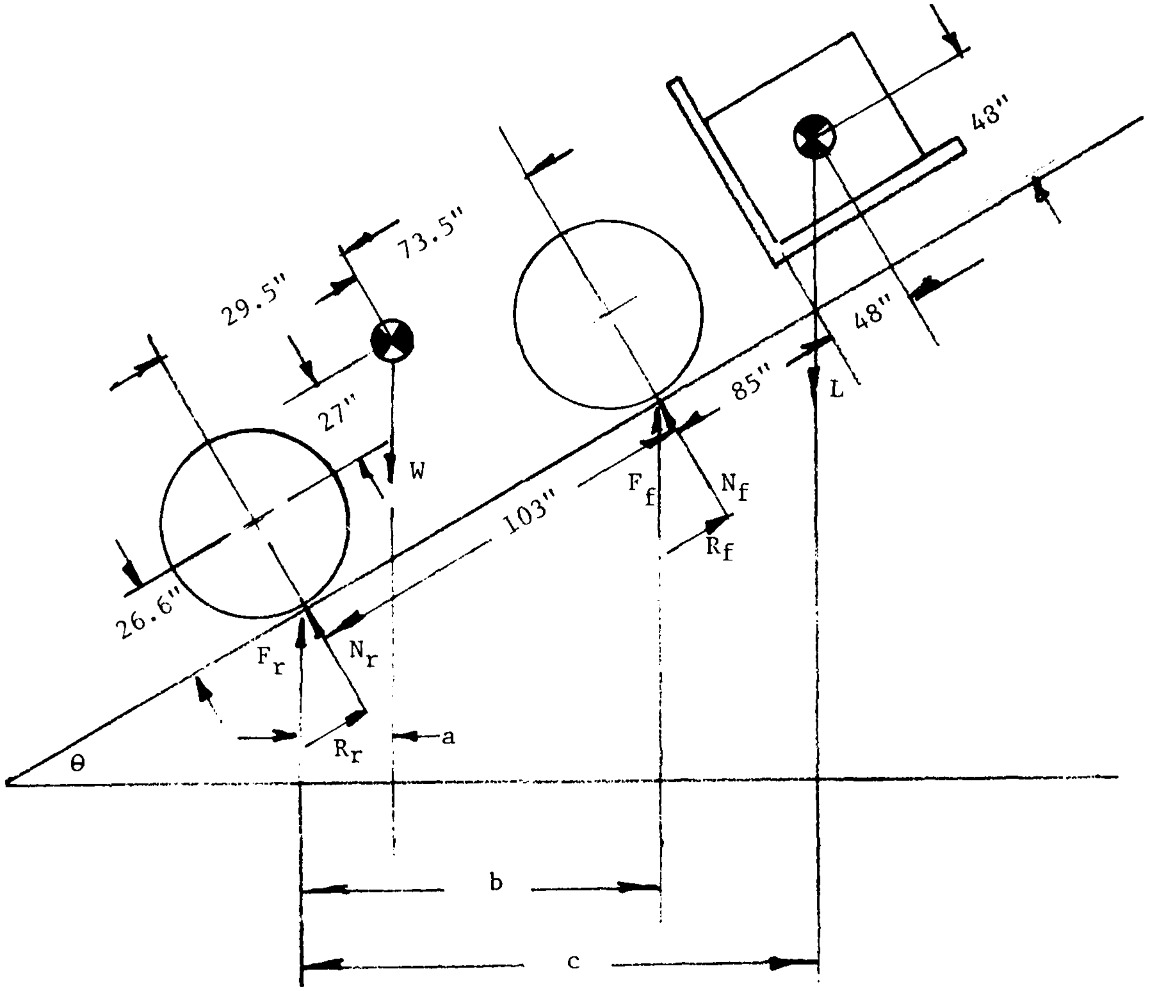
- engine
- torque converter
- transmission
- drive shafts and universal joints
- axle including final drive.

As noted in Section 5.1.3, if the transmission is modified to provide a low enough gear ratio to raise the rear wheel speed to 45 mph, the input shaft speed to the drive axles for the two larger vehicles will exceed the normal limit of 3500 rpm. If the axle ratio is reduced in order to limit this input speed, other changes are required to produce enough low speed torque to meet the gradeability requirement. Thus, in general, the entire drivetrain must be considered at the same time.

The requirements for the drivetrain are:

- At a wheel speed of 45 mph.
  - the input shaft speed to the axle should be 3500 rpm or less.
  - the torque delivered to the wheels must be capable of maintaining 45 mph, taking into account wind resistance, losses, and a grade requirement (usually 2% or 5%).
- At a wheel speed of 2 mph.
  - the torque delivered to the wheels must be capable of overcoming losses and the grade requirement of 45%.

The torque required to ascend or overcome a grade can easily be computed, knowing the weight distribution and geometry of the vehicle. As an example, Figure 28 shows a loaded M10A on a 45% grade. The principal geometrical variables needed to calculate the wheel torques are shown on the diagram. The position of the forks had to be assumed for this calculation.


73.5"
29.5"
27"
26.6"
W
48"
48"
85"
L
103"
F_f
N_f
R_f
F_r
N_r
R_r
a
θ
b
c

tan θ = 0.45, θ = 24.2277°

x = (27 + 26.6) tan θ = 24.12"

a = (29.5 - x)cos θ = 4.9061"

b = 103 cos θ = 93.9279"

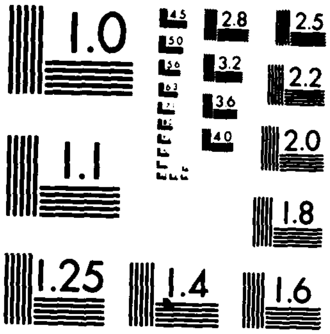
c = (103 + 85 + 48 - 48 tan θ) cos θ

= 195.516

Figure 28

Schematic Diagram of the M10A on a 45% Grade with Principal Geometrical Parameters

AD-A170 798 FEASIBILITY OF ROUGH TERRAIN FORKLIFT TRUCKS WITH A 2/3
ROAD SPEED CAPABILITY OF 45 MPH(U) LITTLE (ARTHUR D)
INC CAMBRIDGE MA J S HOWLAND MAY 86 ADL-54964
UNCLASSIFIED DAAK70-85-C-0112 F/G 13/6 NL


1.0
4.5
5.0
5.6
6.3
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Taking the moment balance about the rear wheel gives,

$$aW - bF_f + cL = 0 \qquad (46)$$

Substituting the values from Figure 28 gives,

$$F_f = 22{,}732 \text{ lbs.}$$

Vertical force equilibrium gives,

$$F_r + F_f = 46{,}700 \text{ lbs.} \qquad (47)$$

which combined with Eq. (46) gives,

$$F_r = 23{,}968 \text{ lbs.}$$

The wheel torques for each wheel are simply,

$$T = R\ F \sin \theta \qquad (48)$$

where R = radius of the tire = 2.216 ft.

Substituting the wheel forces gives,

$$T_f = 20{,}368 \text{ ft. lbs.}$$

$$T_r = 21{,}803 \text{ ft. lbs.}$$

This type of calculation was used to calculate the required wheel torques to overcome various grades for the three vehicles of interest and upgraded versions of these vehicles. For purposes of the torque calculation, the upgraded versions include a weight increase to account for heavier drive components.

The results of these calculations are shown in Tables 11 through 13 for the three vehicles. In addition, the torque required to overcome the rolling resistance of the vehicles is shown. This is based on a rule of thumb used by the axle manufacturers of 20 lbs. of rolling resistance per 1000 lbs. of vehicle weight. The torque is calculated knowing the tire radii of the vehicles.

The only torque not taken into account in Tables 11-13 is that required to overcome wind resistance. Instead, that requirement will be taken into account as an added power requirement, principally at 45 mph. The torques calculated in this section will be used to select and evaluate candidate driveline components in Section 7.

6.5 BRAKES

It was seen in Section 5.4 that the RTFLT's, especially the larger vehicles, will be marginally stable at 45 mph. In this situation, the capability of the brake system to provide safe controlled stops without skidding can be important in maintaining driver control of the vehicle.

The brake systems used on the current vehicles vary. For example, the M10A uses air over hydraulically actuated dry-disc brakes with independent circuits for each axle. The Gradall machine uses hydraulic drum brakes on the front axle and dynamic braking with the hydrostatic transmission on the rear wheels.

The capacity of the brake systems is not likely to be a problem at 45 mph. They should be sized to be capable of producing a full-skid and this torque requirement will not change significantly at higher speed.

Table 11

Torque Requirements for the 4K RTFLT

Parameter	Current M4K		Upgraded Vehicle	
	Unloaded	Loaded	Unloaded	Loaded
Vehicle Weight, lbs.	9,900	13,900	12,000	16,000
Front Axle Load	4,769	10,948	5,781	12,602
Rear Axle Load	5,131	2,952	6,219	3,398
Wheel torque (ft. lbs.) to overcome				
2% grade	300	422	364	485
5% grade	750	1,053	909	1,212
45% grade	6,161	8,651	7,469	9,958
Wheel torque to overcome rolling resistance	300	422	364	485

Table 12

Torque Requirements for the 6K RTFLT

Parameter	Gradall 534B		Upgraded Vehicle	
	Unloaded	Loaded	Unloaded	Loaded
Vehicle Weight, lbs.	18,000	24,000	20,000	26,000
Wheel Torque (ft. lbs.) to overcome				
2% Grade	723	964	803	1,044
5% Grade	1,805	2,407	2,006	2,608
45% Grade	14,835	19,780	16,483	21,428
Wheel torque to overcome rolling resistance	360	480	400	520

Table 13

Torque Requirements for the 10K RTFLT

Parameter	Current M10A		Upgraded Vehicle	
	Unloaded	Loaded	Unloaded	Loaded
Vehicle Weight, lbs.	36,499	46,499	49,000	59,000
Wheel torque (ft. lbs.) to overcome				
2% Grade	1,618	2,061	2,171	2,615
5% Grade	4,040	5,147	5,424	6,531
45% Grade	33,201	42,297	44,572	53,669
Wheel torque (ft. lbs.) to overcome rolling resistance	730	930	980	1,180

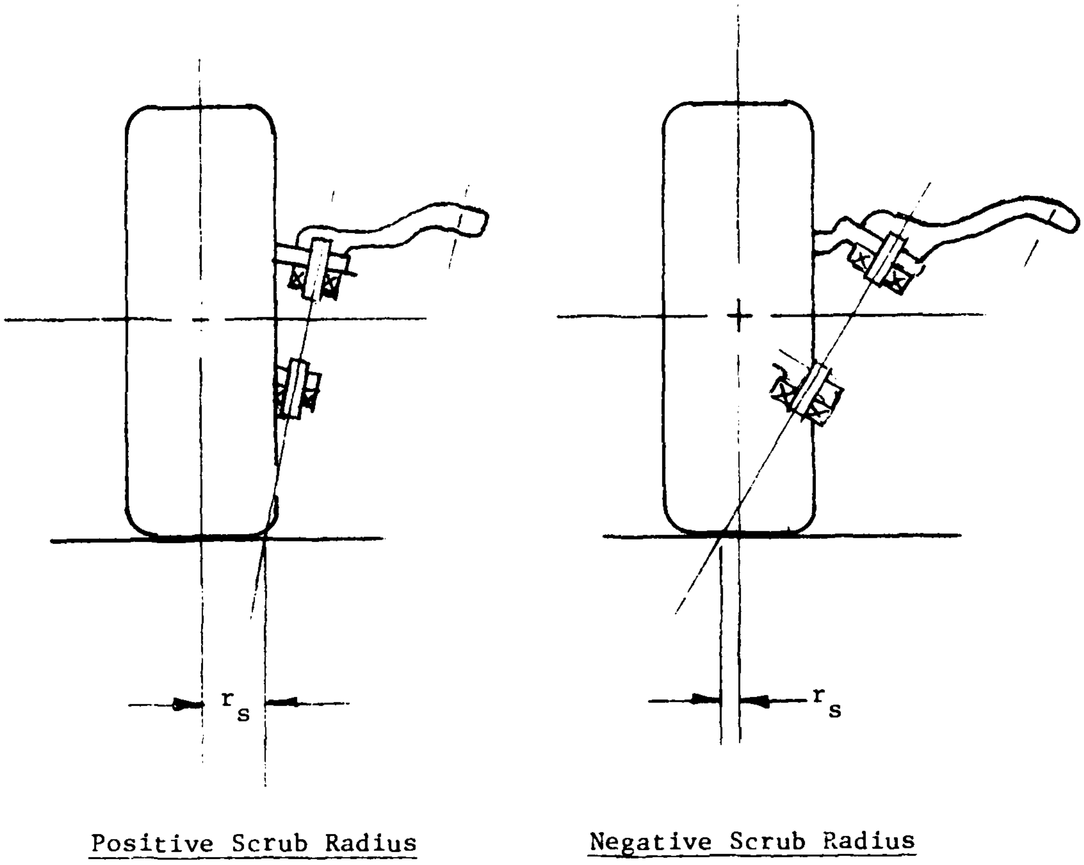
However, improved stability may be necessary for good handling characteristics in a hard stop. Because of the relatively high center-of-mass, these vehicles will have significant longitudinal load transfer during high decelerations. This will have a tendency to unload the rear wheels and cause skid or rear end breakaway. Load proportioning to regulate the front to rear pressure may be used to avoid rear wheel skidding. This is commonly done on highway trucks. Automobiles with front disc brakes and rear drum brakes also contain a proportioning valve which is a standard brake system component. Unloading at high decelerations is sometimes incorporated by providing a special control which senses body angle.

Another method for avoiding skid is the incorporation of an anti-skid or anti-lock brake control. The Bosch electronic pulsed system has recently been available on production automobiles and several systems are likely to be available soon as off-the-shelf components.

Stability during braking is also affected by the scrub radius for systems using a steering axle. As illustrated in Figure 29, the scrub radius, r_s, is determined by the distance between the intersection of the kingpin pivot axis with the ground and the center of the tire footprint. If this radius is positive, uneven braking force will cause one wheel to deflect outward toward the higher braking force and, thus, produce an undesirable outward steering moment. Negative scrub radius, produces inward deflection resulting in stabilizing tire forces.

Many of the higher capacity planetary steering axles employ a vertical kingpin axis which, of course, produces a very large positive scrub radius. At low speeds, this may not be serious, but at high speeds, it is likely to cause unstable handling characteristics during braking and undesirable sensitivity to bumps and irregularity in the road surface.

Thus, if Ackerman steering is to be used on any of these vehicles operating at 45 mph, it is recommended that the steering axle incorporate a design which provides minimum positive or negative scrub radius.



Positive Scrub Radius

Negative Scrub Radius

FIGURE 29 DIAGRAM ILLUSTRATING SCRUB RADIUS

6.6 OTHER COMPONENTS

Because of their importance to the feasibility of 45 mph RTFLT's, the discussion has centered around the suspension system, steering system, drivetrain, and tires. A number of other components which are not as critical to basic feasibility, should also be considered in a final vehicle specification.

6.6.1 Driver Safety

The current vehicle specifications call for roll-over protective structures, driver restraints, and driver seats which conform to applicable SAE standards and should be adequate for highway operation. However, if the final vehicle design selected requires constant driver attention and control to maintain stability, consideration should be given to the addition of a sleep warning system for the driver. The highest fatality rate for surface mining operations was, at one time, due to the drivers of wheel loaders falling asleep during high-speed tramming operation. The vehicle would then jack-knife and tip over.

It is believed that a sleep warning system would be a development item. However, several years ago, the Bureau of Mines was conducting research on the subject and a prototype system may have resulted.

6.6.2 Visibility

The current specification for headlamps conforms to the relevant SAE standards but these should be reviewed for adequacy at highway speeds.

Rearview mirrors should be added to the specification for highway operation.

7. COMMERCIAL AVAILABILITY STUDY - PHASE III

7.1 TIRES

7.1.1 General Discussion

At the outset of the study, it was clear that there is a potential problem or limitation operating at 45 mph with the tires used on the current RTFLT's. These tires are typically rated at 5 mph.

Off-the-road tires are designed for high strength and durability. They typically have a lot of plys and rubber. The major problem with operating them at high speed is due to heat build up which leads to tread separation, accelerated wear, and susceptibility to damage.

Generally, this requires that a given tire, under specified load and inflation conditions, must be limited to a maximum distance or period of time at which point it must be allowed to cool down.

Two industry rating standards apply to this type of service at speeds of interest in this study:

- Mining and Logging Service

  This service limits the operation of the tires to 55 mph and the total distance to 55 miles in any 1 1/2 hour period. The Tire and Rim Association standards which apply to this service are shown in Tables 14-16. (25)

- Off-The-Road Haulage Service

  This service limits the operation of the tires to 40 mph and a distance of 2.5 miles. The Tire and Rim Association standards which apply to this service are shown in Tables 17-20.

TABLE 14

DIAGONAL (BIAS) PLY
MINING AND LOGGING TIRES USED IN INTERMITTENT HIGHWAY SERVICE

TIRE AND RIM ASSOCIATION STANDARD

TIRE TYPE NOMENCLATURE	
Code No.	**Tire Type**
ML-1	Rib
ML-2	Traction
ML-3	Rock
ML-4	Rock Deep Tread

TABLE TB-5ML
MAXIMUM SPEED — **55** MILES PER HOUR
DISTANCE MUST NOT EXCEED 55 MILES IN ANY 1½ HOUR PERIOD

TIRE SIZE DESIGNATION	TIRE LOAD LIMITS (LBS.) AT VARIOUS COLD INFLATION PRESSURES (PSI)																
	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105
7.00-16 ML	1200	1330	1460	1570	1690	**1790**(C)											
8.25-20 ML	1870	2080	2270	2460	2640	2800	2960	3120	3270	3410	**3550**(E)	3690	3820	**3950**(F)			
9.00-20 ML	2210	2460	2690	2910	3120	3310	**3510**(D)	3690	3870	**4040**(E)	4200	4360	**4520**(F)	4670	4820	**4970**(G)	
10.00-20 ML	2500	2790	3050	3300	3530	3760	3970	4180	4380	4580	**4760**(F)	4950	5120	**5300**(G)			
10.00-22 ML	2660	2970	3240	3510	3760	4000	4230	4450	4660	4870	**5070**(F)	5260	5450	**5640**(G)			
10.00-24 ML	2830	3150	3440	3720	3990	4240	4490	4720	4950	5170	**5380**(F)	5590	5790	**5990**(G)			
11.00-20 ML	2730	3040	3320	3590	**3850**(D)	4100	4330	**4560**(E)	4780	4990	**5190**(F)	5390	5590	**5780**(G)			
11.00-22 ML	2900	3230	3530	3820	4090	4350	4600	4840	5080	5300	**5520**(F)	5730	5940	**6140**(G)	6330	6530	**6720**(H)
11.00-24, 25 ML	3080	3430	3750	4050	4340	4620	4890	5140	5390	5630	**5860**(F)	6090	6310	**6520**(G)	6730	6930	**7130**(H)
TIRES MOUNTED ON 15° DROP CENTER RIMS																	
9-22.5 ML	1870	2080	2270	2460	2640	2800	2960	3120	3270	3410	**3550**(E)						
10-22.5 ML	2210	2460	2690	2910	3120	3310	3510	3690	3870	**4040**(E)	4200	4360	**4520**(F)				
11-22.5 ML	2500	2790	3050	3300	3530	3760	3970	4180	4380	4580	**4760**(F)	4950	5120	5300	5470	**5630**(H)	
11-24.5 ML	2660	2970	3240	3510	3760	4000	4230	4450	4660	4870	**5070**(F)	5260	5450	**5640**(G)			
12-22.5 ML	2730	3040	3320	3590	3850	4100	4330	4560	4780	4990	**5190**(F)	5390	5590	**5780**(G)			

NOTES
1. Letters in parentheses denote the load range for which bold face loads are maximum.
2. Mining and Logging tires are not intended for sustained highway service.
3. Load Limits for Mining and Logging Tires used at reduced speeds on improved surfaces - See Page **2**-36.
4. General Data shown on Page **2**-31.

CAUTION - ALWAYS USE APPROVED TIRE AND RIM COMBINATIONS FOR DIAMETERS AND CONTOURS. SEE PAGE **2**-31 FOR APPROVED TIRE AND RIM COMBINATIONS.

FOR RIM AND WHEEL LOAD INFORMATION, SEE PAGE **2**-05.

TABLE 15

MINING AND LOGGING TIRES USED IN INTERMITTENT HIGHWAY SERVICE

TIRE AND RIM ASSOCIATION STANDARD

TIRE TYPE NOMENCLATURE	
Code No	Tire Type
ML-1	Rib
ML-2	Traction
ML-3	Rock
ML-4	Rock Deep Tread

TABLE TB-7ML

MAXIMUM SPEED **50** MILES PER HOUR

DISTANCE MUST NOT EXCEED 50 MILES IN ANY [illegible] HOUR PERIOD

TIRE LOAD LIMITS [illegible]

TIRE SIZE DESIGNATION	RADIAL PLY																
	30	35	40	45	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	105	110
	DIAGONAL (BIAS) PLY																
	25	30	35	40	45	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	90	95	100	105
[illegible] 21 ML	[illegible]	3460	3780	4090	4380	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**6140**	[illegible]	6580	**6790**(H)	7000	**7200**(J)
[illegible] ML	[illegible]	3890	4260	4600	4930	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**6910**	[illegible]	7410	**7640**(H)	7870	**8100**(J,L)
[illegible] 24 ML	4060	4510	4960	5330	5710	6080	[illegible]	[illegible]	[illegible]	**7400**	[illegible]	[illegible]	**8290**(H)	8570	8840	**9120**(J)	
[illegible] 21 ML	4270	4750	5200	5620	6020	[illegible]	**6770**	[illegible]	[illegible]	**7800**	[illegible]	[illegible]	**8740**	9040	9320	**9610**(L)	
[illegible] 24.25 ML	4750	5300	5800	6270	6720	[illegible]	[illegible]	[illegible]	[illegible]	**8710**	[illegible]	[illegible]	**9750**	10030	10410	**10730**(L,N)	

Tire size designation will include "R" (Radial Ply) or "[illegible]" (Diagonal or Bias Ply)

NOTES 1. Letters in parentheses denote the load range for which bold face loads are maximum

2. Mining and Logging tires are not intended for sustained highway service

3. Load limits for Mining and Logging Tires used at reduced speeds on improved surfaces See Page 2-36

CAUTION — ALWAYS USE APPROVED TIRE AND RIM COMBINATIONS FOR DIAMETERS AND CONTOURS. SEE PAGE 2-33 FOR APPROVED TIRE AND RIM COMBINATIONS.

FOR RIM AND WHEEL LOAD INFORMATION, SEE PAGE 2-05

TABLE 16

DIAGONAL (BIAS) PLY
MINING AND LOGGING TIRES USED IN INTERMITTENT HIGHWAY SERVICE

WIDE BASE TIRES MOUNTED ON 15 DROP CENTER RIMS

TIRE AND RIM ASSOCIATION STANDARD

TIRE TYPE NOMENCLATURE	
Code No.	Tire Type
ML-1	Rib
ML-2	Traction
ML 3	Rock
ML-4	Rock Deep Tread

TABLE WBTB-2ML
MAXIMUM SPEED—**55** MILES PER HOUR
DISTANCE MUST NOT EXCEED 55 MILES IN ANY 1½ HOUR PERIOD

[illegible]	DUAL [illegible]	TIRE LOAD LIMITS (LBS.) AT VARIOUS COLD INFLATION PRESSURES (PSI)														
		30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
14-17.5ML	D	**2820**(C)	3080	3340	**3570**(D)	3800	4020	**4220**(E)	4430	4620	**4810**(F)	5000	5180	**5360**(G)		
	S			**3210**(C)	3500	3790	**4060**(D)	4320	4570	**4800**(E)	5030	5255	**5470**(F)	5680	5890	**6090**(G)
15-19.5ML	S			**4090**(D)	4470	4830	**5180**(E)	5510	5820	**6130**(F)	6420	6710	**6980**(G)			
15-22.5ML	S						**5680**(E)	6040	6390	**6720**(F)	7040	7360	**7660**(G)	7950	8240	**8520**(H)
16.5-22.5ML	S						6590	7010	7410	[illegible]	[illegible]	8540	[illegible]	**9230**(H)		
18-19.5ML	S						6700	7130	7540	7930	8310	8680	**9040**(H)			
18-22.5ML	S						7310	7780	8220	8650	9070	9470	**9860**(H)	10240	10610	**10970**(J)

NOTES 1. Letters in parentheses denote the load range for which bold face loads are maximum.

2. Mining and Logging tires are not intended for sustained highway service.

3. Load Limits for Mining and Logging Tires used at reduced speeds on improved surfaces - See Page **2**-36.

CAUTION ALWAYS USE APPROVED TIRE AND RIM COMBINATIONS FOR DIAMETERS AND CONTOURS. SEE PAGE **2**-35 FOR APPROVED TIRE AND RIM COMBINATIONS
FOR RIM AND WHEEL LOAD INFORMATION, SEE PAGE **2**-05.

TABLE 17

OFF-THE-ROAD HAULAGE SERVICE — 40 MPH MAXIMUM SPEED

CONVENTIONAL DIAGONAL (BIAS) PLY TIRES

TIRE AND RIM ASSOCIATION STANDARD

TABLE C-40
DISTANCE — Up to 2.5 miles (one way)

TIRES SIZE DESIGNATION	TIRE LOAD LIMITS (LBS) AT VARIOUS COLD INFLATION PRESSURES (PSI)								
	40	45	50	55	60	65	70	75	80
12.00-20, 21 NHS	4100	4380	4660	4940	**5180**(14)	5440	**5680**(16)		
12.00-24, 25 NHS	4600	4940	5240	5540	**5840**(14)	6100	**6400**(16)		
13.00-24, 25 NHS	5320	5700	6050	6400	6750	7050	**7400**(18)		
14.00-20, 21 NHS	5620	6050	6400	6800	**7150**(16)	7450	7800	**8100**(20)	
14.00-24, 25 NHS	6300	6750	7150	7550	**7950**(16)	8350	8700	**9050**(20)	*9400(24)
16.00-21 NHS	7500	**8000**(16)	8550	9000	**9500**(20)				
16.00-25	8200	8800	9350	9900	**10400**(20)	10900	**11400**(24)	11900	**12300**(28)
18.00-25	**10600(16)	11400	**12100**(20)	12800	**13500**(24)	14100	**14700**(28)	15300	**15900**(32)
18.00-33	12300	13200	14000	14800	**15600**(24)	16300	**17100**(28)	17800	**18500**(32)
18.00-49	15600	16700	17700	18700	**19700**(24)	20700	**21600**(28)	22500	**23300**(32)
21.00-25	13700	14600	**15600**(24)	16400	**17300**(28)	18100	**18900**(32)		
21.00-35	16200	17400	18500	19500	**20500**(28)	21500	**22500**(32)	23400	**24300**(36)
21.00-49	19600	21000	22400	23600	24900	26100	**27200**(32)	28400	**29400**(36)
24.00-25	17600	**18900**(24)	20100	**21300**(30)					
24.00-29	18900	**20200**(24)	21500	**22800**(30)	23900	**25100**(36)			
24.00-35	20700	22200	23600	**25000**(30)	26300	**27500**(36)	28700	**29900**(42)	
24.00-49 27-56.5	24900	26600	28300	**29900**(30)	31500	**33000**(36)	34500	**35900**(42)	***37300(48)
27.00-33	24800	26500	**28200**(30)	29800	**31400**(36)				
27.00-49 30-56.5	30400	32600	34700	36700	**38600**(36)	40400	**42200**(42)	44000	**45700**(48)
30.00-51 33-59.5	37700	40400	42900	45400	47800	50100	**52300**(46)	54400	**56500**(52)
33.00-51 36-59.5	43700	46800	49700	52600	55300	58000	**60500**(50)	63000	**65500**(58)
36.00-51 39.59.5	53200	56900	60500	**64000**(42)	67500	**70500**(50)	73500	**77000**(58)	
40.00-57	68000	72500	77500	82000	86000	90000	**94000**(60)	98000	**102000**(68)

*Maximum 10100 at 90 psi (24)

**Maximum 8950 at 30 psi (12)

***Maximum 38600 at 85 psi (48)

NOTES 1: Figures in parentheses denote ply rating for which bold face loads and inflations are maximum.

2: Refer to Page 3-02 for tire selection procedure.

3: Recommended shipping pressures are the maximum inflation pressures for the tire sizes and ply ratings shown.

GENERAL DATA SHOWN ON PAGES 3-22 AND 3-24.

FOR RIM AND WHEEL LOAD INFORMATION, SEE NOTE 3, PAGE 3-29.

TABLE 18

OFF-THE-ROAD HAULAGE SERVICE — 40 MPH MAXIMUM SPEED
WIDE BASE DIAGONAL (BIAS) PLY TIRES

TIRE AND RIM ASSOCIATION STANDARD

TABLE WB-40

DISTANCE — Up to 2.5 miles (one way)

TIRES SIZE	TIRE LOAD LIMITS (LBS.) AT VARIOUS COLD INFLATION PRESSURES (PSI)						
DESIGNATION	25	30	35	40	45	50	55
15.5-25	**4720**(8)	5240	**5740**(12)				
17.5-25	5640	6250	**6850**(12)	7400	**7950**(16)	8450	**8950**(20)
20.5-25	7550	**8400**(12)	9150	**9900**(16)	10600	**11300**(20)	
23.5-25	**9600**(12)	10700	**11700**(16)	**12700**(20)	13600	**14400**(24)	
26.5-25	12100	13400	**14700**(20)	15900	**17000**(24)	**18100**(26)	**19200**(28)
26.5-29	12900	14400	15700	**17000**(22)	18200	**19400**(26)	
29.5-25	14600	16200	**17700**(22)	19200	**20500**(28)		
29.5-29	15500	17300	**18900**(22)	20400	**21900**(28)	23300	**24600**(34)
29.5-35	16900	18800	20600	22200	**23800**(28)	25300	**26800**(34)
33.25-29	19100	21300	**23300**(26)	25100	**26900**(32)		
33.25-35	20700	23000	25200	27300	**29200**(32)	31100	**32800**(38)
33.5-33	20900	23200	25400	27500	**29400**(32)	31300	**33100**(38)
33.5-39	22500	25000	27300	29600	**31700**(32)	33700	**35600**(38)
37.25-35	25000	27800	30400	**32800**(30)	**35200**(36)	37400	**39600**(42)
37.5-33	25100	27900	30500	**33000**(30)	**35400**(36)	37600	**39800**(42)
37.5-39	26900	29900	32800	35400	**38000**(36)	40400	**42700**(44)
37.5-51	30400	33900	37100	40100	**42900**(36)	45700	**48300**(44)

NOTES 1: Figure in parentheses denote ply rating for which bold face loads and inflations are maximum.
2: Refer to Page 3-02 for tire selection procedure.
3: Recommended shipping pressures are the maximum inflation pressures for the tire sizes and ply ratings shown.

GENERAL DATA SHOWN ON PAGE 3-26.

FOR RIM AND WHEEL LOAD INFORMATION, SEE NOTE 3, PAGE 3-29

TABLE 19

OFF-THE-ROAD HAULAGE SERVICE — 40 MPH MAXIMUM SPEED

CONVENTIONAL RADIAL PLY TIRES

TIRE AND RIM ASSOCIATION STANDARD

TABLE CR-40
DISTANCE — *Up to 2.5 miles (one way)*

TIRE SIZE DESIGNATION	TIRE LOAD LIMITS (LBS.) AT VARIOUS COLD INFLATION PRESSURES (PSI)								
	60	65	70	75	80	85	90	95	100
12.00R20, 21 NHS	4660	4940	**5180** ★	5440	5680	5920	6150	6350	**6600** ★ ★
12.00R24, 25 NHS	5240	5540	**5840** ★	6100	6400	6650	6900	7150	**7400** ★ ★
13.00R24, 25 NHS	6050	6400	**6750** ★	7050	7400	7700	8000	8250	**8550** ★ ★
14.00R20, 21 NHS	6400	6800	**7150** ★	7450	7800	8100	8450	8750	**9050** ★ ★
14.00R24, 25 NHS	7150	7550	**7950** ★	8350	8700	9050	9400	9750	**10100** ★ ★
16.00R21 NHS	8550	9000	**9500** ★	9950	10400	10800	11200	11600	**12000** ★ ★
16.00R25	9350	9900	**10400** ★	10900	11400	11900	12300	12800	**13200** ★ ★
18.00R25	12100	12800	**13500** ★	14100	14700	15300	15900	16500	**17100** ★ ★
18.00R33	14000	14800	**15600** ★	16300	17100	17800	18500	19100	**19800** ★ ★
18.00R49	17700	18700	**19700** ★	20700	21600	22500	23300	24200	**25000** ★ ★
21.00R25	15600	16400	**17300** ★	18100	18900	19700	20500	21200	**21900** ★ ★
21.00R35	18500	19500	**20500** ★	21500	22500	23400	24300	25200	**26000** ★ ★
21.00R49	22400	23600	**24900** ★	26100	27200	28400	29400	30500	**31500** ★ ★
24.00R25	20100	21300	**22400** ★	23400	24500	25500	26500	27400	**28300** ★ ★
24.00R29	21500	22800	**23900** ★	25100	26200	27300	28300	29400	**30400** ★ ★
24.00R35	23600	25000	**26300** ★	27500	28700	29900	31100	32200	**33300** ★ ★
24.00R49	28300	29900	**31500** ★	33000	34500	35900	37300	38600	**39900** ★ ★
27.00R33	28200	29800	**31400** ★	32900	34400	35800	37200	38500	**39800** ★ ★
27.00R49	34700	36700	**38600** ★	40400	42200	44000	45700	47300	**48900** ★ ★
30.00R51	42900	45400	**47800** ★	50100	52300	54400	56500	58600	**60500** ★ ★
33.00R51	49700	52600	**55300** ★	58000	60500	63000	65500	68000	**70000** ★ ★
36.00R51	60500	64000	**67500** ★	70500	73500	77000	79500	82500	**85500** ★ ★
40.00R57	77500	82000	**86000** ★	90000	94000	98000	102000	105500	**109000** ★ ★

NOTE 1: Bold face figures denote maximum load for symbols shown.
GENERAL DATA SHOWN ON PAGES 3-23 AND 3-25.
FOR RIM AND WHEEL LOAD INFORMATION, SEE NOTE 3, PAGE 3-29

TABLE 20

OFF-THE-ROAD HAULAGE SERVICE — 40 MPH MAXIMUM SPEED

WIDE BASE RADIAL PLY TIRES

TIRE AND RIM ASSOCIATION STANDARD

TABLE WBR-40
DISTANCE — Up to 2.5 miles (one way)

TIRE SIZE DESIGNATION	TIRE LOAD LIMITS (LBS.) AT VARIOUS COLD INFLATION PRESSURES (PSI)							
	40	45	50	55	60	65	70	75
15.5R25	5240	5740	6200	**6650★**	7100	7500	7850	**8250★★**
17.5R25	6250	6850	7400	**7950★**	8450	8950	9400	**9850★★**
20.5R25	8400	9150	9900	**10600★**	11300	11900	12600	**13200★★**
23.5R25	10700	11700	12700	**13600★**	14400	15300	16100	**16800★★**
26.5R25	13400	14700	15900	**17000★**	18100	19200	20200	**21100★★**
26.5R29	14400	15700	17000	**18200★**	19400	20500	21500	**22600★★**
29.5R25	16200	17700	19200	**20500★**	21800	23100	24300	**25500★★**
29.5R29	17300	18900	20400	**21900★**	23300	24600	25900	**27100★★**
29.5R35	18800	20600	22200	**23800★**	25300	26800	28200	**29500★★**
33.25R29	21300	23300	25100	**26900★**	28700	30300	31900	**33400★★**
33.25R35	23000	25200	27300	**29200★**	31100	32800	34600	**36200★★**
33.5R33	23200	25400	27500	**29400★**	31300	33100	34800	**36500★★**
33.5R39	25000	27300	29600	**31700★**	33700	35600	37500	**39300★★**
37.25R35	27800	30400	32800	**35200★**	37400	39600	41600	**43600★★**
37.5R33	27900	30500	33000	**35400★**	37600	39800	41800	**43800★★**
37.5R39	29900	32800	35400	**38000★**	40400	42700	44900	**47100★★**
37.5R51	33900	37100	40100	**42900★**	45700	48300	50800	**53200★★**

NOTE 1: Bold face figures denote maximum load for symbols shown.
GENERAL DATA SHOWN ON PAGE 3-27.
FOR RIM AND WHEEL LOAD INFORMATION, SEE NOTE 3, PAGE 3-29.

In addition to these general industry standards, speed-load-pressure data for a number of tires used in mobile crane applications is supplied by Michelin. (26) These are summarized in the useful sizes in Tables 21-24.

Finally, Michelin publishes a highway speed load vs. pressure rating for their XL All-Terrain tires which are often used for military applications. The table of data for this series is shown in Table 25.

It should be emphasized that the data shown in this section was the only specific data found which rates tires at speeds approaching or exceeding 45 mph.

It is quite likely that many of the off-road tires not covered by this data could be used under favorable conditions at 45 mph. Favorable conditions generally involve high inflation pressures, low loads, and limited periods of time at speed. However, the manufacturers suggest that any application outside the recommended range should be tested.

7.1.2 4K RTFLT

The individual tire load for the 4K RTFLT will likely be about 2900 lbs., unloaded, after it has been upgraded for 45 mph operation. Maximum loaded tire load will be about 6000 lbs.

The current tire size for the M4K is 15 x 19.5 - 8PR inflated to 45 psi. The ML version of this tire is rated to 55 mph for 55 miles in a 1 1/2 hour period as shown in Table 16. In addition, there are three 20-inch crane tires shown in Tables 21 through 23, each of which has ample load capacity at 45 mph and 90 psi inflation. Finally, Table 25 shows a number of 20-inch tires with highway speed load ratings above 6000 lbs.

Thus, it appears almost certain that an acceptable tire can be found for the high-speed 4K RTFLT. The required inflation pressure is likely to be much higher than 45 psi, probably over 70 psi. In fact, it may prove expedient to design the vehicle to allow high pressures for highway operation and somewhat lower pressures where off-road mobility is required

TABLE 21

MICHELIN TIRE SPECIFICATIONS

CRANE APPLICATION

SIZE	PLY RATING
10.00R20X	PR14-LRG PR16-LRH

LOADS PER AXLE (LBS) AT VARIOUS INFLATION PRESSURES (PSI)

(S) = SINGLE — 2 TIRES
(D) = DUAL — 4 TIRES

Speed (mph)		90psi	95psi	100psi	105psi	110psi	115psi	120psi	125psi	130psi
0	S			22,540	23,460	24,380	25,315	26,260	27,165	28,165[2]
	D			40,585	42,235	43,890	45,565	47,255	48,895	50,695[2]
0-3	S			18,935	19,710	20,480	21,265	22,055	22,820	23,660[2]
	D			34,090	35,480	36,865	38,275	39,695	41,070	42,585[2]
5	S		16,535	17,250	17,965	18,700	19,410	20,165	20,955	21,745[2]
	D		29,770	31,050	32,340	33,655	34,930	36,295	37,730	39,165[2]
10	S	14,975	15,655	16,335	17,035	17,715	18,425	19,180	19,930[2]	20,475[3]
	D	26,960	28,180	29,400	30,655	31,880	33,165	34,530	35,905[2]	36,855[3]
20	S	12,330	12,915	13,485	14,090	14,720[2]	15,280	15,720	16,125[3]	
	D	22,195	23,240	24,265	25,365	26,510[2]	27,520	28,410	29,445[3]	
30	S	11,575	12,115	12,695	13,290[2]	13,785	14,190	14,575[3]		
	D	20,830	21,800	22,850	23,935[2]	24,820	25,755	26,475[3]		
40	S	11,540	12,090	12,690[1]	13,255	13,675	14,055[3]			
	D	20,765	21,765	22,845[1]	23,870	24,675	25,670[3]			
50	S	11,190	11,750	12,330[1]	12,815	13,205	13,580[3]			
	D	20,140	21,150	22,205[1]	23,070	23,995	24,620[3]			

TABLE 22

MICHELIN TIRE SPECIFICATIONS

CRANE APPLICATION

SIZE	PLY RATING
11.00R20X	PR14-LRG PR16-LRH

LOADS PER AXLE (LBS) AT VARIOUS INFLATION PRESSURES (PSI)

(S) = SINGLE — 2 TIRES
(D) = DUAL — 4 TIRES

Speed (mph)		90psi	95psi	100psi	105psi	110psi	115psi	120psi	125psi	130psi
0	S			23,795	24,790	25,780	26,770	27,700	28,385	29,525[2]
	D			42,150	43,900	45,650	47,400	49,155	50,940	52,620[2]
0-3	S			19,990	20,820	21,655	22,485	23,270	23,845	24,800[2]
	D			35,405	36,875	38,345	39,815	41,290	42,790	44,200[2]
5	S		17,460	18,230	19,000	19,770	20,325	21,120	22,000	22,600[2]
	D		30,930	32,285	33,640	35,000	36,380	37,705	38,955	40,140[2]
10	S	15,810	16,540	17,275	18,010	18,570	19,290	20,140	20,775	21,550[2]
	D	28,000	29,295	30,590	31,885	33,195	34,465	35,665	36,795	39,040[2]
20	S	13,040	13,652	14,115	14,775	15,420	16,000[2]	16,620	17,200[3]	
	D	23,090	24,170	25,275	26,325	27,305	28,625[2]	30,065	30,460[3]	
30	S	12,235	12,675	13,720	13,900	14,470[2]	15,035	15,660[3]		
	D	21,665	22,710	23,700	25,490	26,750[2]	27,000	27,715[3]		
40	S	12,145	12,640	13,320	13,845	14,450[2]	14,990[3]			
	D	21,610	22,635	23,590	24,660	26,195[2]	26,550[3]			
50	S	11,725	12,320	12,900	13,455	14,000[2]	14,635[3]			
	D	20,970	21,945	22,845	24,230	25,090[2]	25,885[3]			

TABLE 23

MICHELIN TIRE SPECIFICATIONS

CRANE APPLICATION

SIZE **12.00R20X**

PLY RATING **PR18-LRJ**

LOADS PER AXLE (LBS) AT VARIOUS INFLATION PRESSURES (PSI)

(S) = SINGLE — 2 TIRES
(D) = DUAL — 4 TIRES

Speed (mph)		90psi	95psi	100psi	105psi	110psi	115psi	120psi	125psi	130psi
0	S				25,985	27,110	28,235	29,345	30,380	31,530
	D				46,290	48,260	50,235	52,175	53,985	56,005
0-3	S				21,830	22,775	23,720	24,650	25,520	26,485
	D				38,880	40,540	42,195	43,825	45,350	47,045
5	S			19,150	20,020	20,890	21,700	22,570	23,440	24,210
	D			34,090	35,620	37,150	38,570	40,095	41,620	42,960
10	S		17,360	18,190	19,020	19,805	20,800	21,460	22,190	23,065
	D		30.915	31,090	33,830	35,200	36,635	38,105	39,375	40,900
20	S	13,725	14,420	15,075	15,775	16,445	17,105	17,800	18,410	19,025
	D	24,425	25,650	26,790	28,020	29,190	30,340	31,565	32,655	33,790
30	S	12,930	13,545	14,215	14,830	15,480	16,110	16,685	17,440	
	D	22,990	24,070	25,245	26,325	27,455	28,565	29,610	30,920	
40	S	12,900	13,530	14,195	14,800	15,470	16,050	16,660		
	D	22,930	24,035	25,200	26,255	27,435	28,470	29,585		
50	S	12,510	13,155	13,760	14,390	15,000	15,560	16,365		
	D	22.235	23,365	24,425	25,525	26,600	27,620	28,995		

TABLE 24

MICEHLIN TIRE SPECIFICATIONS

CRANE APPLICATION

SIZE	TYPE	STRENGTH INDEX
14.00R24	XVC	•••

LOADS PER TIRE (LBS) AT VARIOUS INFLATION PRESSURES (PSI)

	72psi	87psi	94psi	102psi	109psi	116psi	123psi	131psi	138psi	145psi
STATIC OR CREEP	22,050	25,570	27,340	29,110	29,990	30,870	31,640	32,080	32,520	32,960
5MPH	14,330	16,540	17,640	18,740	19,290	19,850	20,290	20,510	20,840	21,060
10MPH	11,910	13,670	14,550	15,440	15,880	16,320	16,760	16,980	17,200	17,420
19MPH	10,800	12,350	13,120	13,890	14,330	14,660	14,990	15,210	15,440	15,550
25MPH	10,360	11 910	12,680	13,450	13,890	14,220	14,550	14,770	14,990	15,100
31MPH	9,920	11,470	12,130	13,010	13,450	13,780	14,110	14,330	14,550	14,660
40MPH	9,260	10,800	11,580	12,350	12,790	13,120	13,450	13,670	13,890	14,001
44MPH	9,040	10,580	11,360	12,130	12,570	12,900	13,230	13,450	13,670	13,780
47MPH	8,820	10,360	11,140	11,910	12,350	12,680	13,010	13,230	13,450	13,560
50MPH	8,600	10,140	10,910	11,690	12,130	12,460	12,790	13,010	13,230	13,340

All Terrain Tires

TABLE 25

XL

A traction-type tire designed primarily for off-the-road applications It offers exceptional grip when working in fields forests, or mountains Popular for military applications

TIRE Size	Tread	PR/ LR	Type	O D (In)	S L R (In)	Overall Width (In)	RPM	Approved Rims	Area (In)	HARD PLATE GROUND CONTACT Length (In)	Width (In)	Max Speed	HIGHWAY SPEED Loads Per Tire @ Pressure
6 50R16	XC Type L	10	TT	27 0	13 5	6 9	712	**4 50E**. 4'.J 5 00F 5 00F 5 50F **4 50E SDC**. 5 00F SDC 5 50F SDC	37 6	8 1	5 0	75	2,200 lb @ 75 PSI
7 00R16	XC Type L	6	TT	30 6	13 9	7 8	679	4 50E 5 00F, 5 50F 6 00JJ, 6 5H 4 50E SDC 5 00E SDC, **5 50F SDC**, 6 00G SDC	45 7	9 5	5 4	75	1,875 lb @ 45 PSI
7 00R16	XC Type L	10	TT	30 6	14 2	7 8	679	4 50, 5 00F, 5 50F, 6 00JJ 6 5H 4 50E SDC, 5 00E SDC, **5 50F SDC**, 6 00G SDC	43 9	8 8	5 4	75	2,540 lb @ 75 PSI
7 50R16	XC* Type L	8	TT	31 6	14 6	8 3	658	5 50F **6 00F**, 6 00JJ 5 50F SDC, **6 00G SDC**, 6 50H SDC	44 6	9 1	5.6	75	2,470 lb @ 65 PSI
9 00R16	XL*	14	Tbls	36 0	16 1	9 5	584	**6.50H**				75	3,085 lb @ 60 PSI
11 00R16	XL*	—	Tbls	38 7	17 8	11 1	536	6 00T **6.50H**, 6 50SC	68 8	11 5	7 2	65	4,520 lb @ 80 PSI
12 5R16 5	XLM	LRC	Tbls	36 5	16 3	11 6	572	**8 25**	92 0	12 5	8 0	65	3,035 lb @ 35 PSI

* Also available in XS

** Pilot

Measuring Rim in Bold Type

TABLE 25
(Continued)

TIRE Size	Tread	PR/ LR	Type	O D (In)	S L R (In)	Overall Width (In)	RPM	Approved Rims	Area (In.)	HARD PLATE GROUND CONTACT Length (In)	Width (In)	Max Speed	HIGHWAY SPEED Loads Per Tire @ Pressure
7.50R20	XL	12	TT	36.5	17.0	8.3	568	**6.0**, 5.5, 6.5	47.4	10.0	5.2	75	3,980 lb @ 95 PSI
8.25R20	XL	14	TT	38.3	17.9	8.9	541	6.0, **6.5**, 7.0	62.0	10.8	6.4	65	4,500 lb @ 95 PSI
9.00R20	XL	14	TT	40.6	18.8	10.0	512	6.5, **7.0**, 7.5	70.4	11.3	7.2	65	5,510 lb @ 105 PSI
10.00R20	XL	16	TT	42.0	19.5	10.8	495	7.0, **7.5**, 8.0	74.7	11.8	7.6	65	6,610 lb @ 115 PSI
10.5R20	XL	8	TT	37.5	17.2	10.9	557	**9.0**	77.0	10.7	7.6	56	3,253 lb @ 50 PSI
11.00R20	XL	16	TT	43.1	20.0	11.2	482	7.33, 7.5, **8.0**, 8.5, 9.0	84.0	11.2	8.7	65	7,200 lb @ 115 PSI
11.00R20	XL	16	Tbls	43.1	20.0	11.2	482	7.33, 7.5, **8.0**, 8.5, 9.0	84.0	11.2	8.7	65	7,200 lb @ 115 PSI
12.00R20	XL*	18	TT	44.3	20.6	11.9	468	7.33, 7.5, 8.0, **8.5**, 9.0	87.1	12.6	8.3	65	8,100 lb @ 120 PSI
12.00R20	XL	18	Tbls	44.3	20.6	11.9	468	7.33, 7.5, 8.0, **8.5**, 9.0	87.1	12.6	8.3	65	8,100 lb @ 120 PSI
12.5R20	XL*	12	TT	40.6	18.4	13.1	516	**11.0**	92.7	12.4	9.1	56	4,190 lb @ 50 PSI
12.5R20	XL*	12	Tbls	40.6	18.4	13.2	516	**11.0**	92.7	12.4	9.1	56	4,190 lb @ 50 PSI
14.75/80R20	XL**	LRJ	TT	45.0	20.5	14.5	465	9.0V, **10.00W,V**	131.9	12.9	11.9	50	10,150 lb @ 125 PSI
14.75/80R20	XL**	LRJ	Tbls	45.0	20.5	14.5	465	9.0V, **10.00W,V**	131.9	12.9	11.9	50	10,150 lb @ 125 PSI
14.00R20	XL*	18	TT	49.4	22.8	14.6	421	9.0, 9.0V, **10.00W,V**	144.2	13.9	12.0	50	9,920 lb @ 100 PSI
14.00R20	XL	18	Tbls	49.4	22.8	14.6	421	9.0, 9.0V, **10.00W,V**	144.2	13.9	12.0	50	9,920 lb @ 100 PSI
15.5/80R20	XL**	LRJ	TT	46.7	21.3	15.1	448	**10.00W**, 11.25	147	12.4	13.2	50	13,118 lb @ 125 PSI
15.5/80R20	XL**	LRJ	Tbls	46.7	21.3	15.1	448	**10.00W**, 11.25	147	12.4	13.2	50	13,118 lb @ 125 PSI
16.00R20	XL*	28	TT	53.1	24.1	15.7	394	**10.00W**, 11.25	178.3	16.0	13.6	40	12,460 lb @ 90 PSI
16.00R20	XL	28	Tbls	53.1	24.1	15.7	394	**10.00W**, 11.25	178.3	16.0	13.6	40	12,460 lb @ 90 PSI
16.00R20	XL Type C	28	TT	53.1	24.1	15.7	394	**10.00W**, 11.25	178.3	16.0	13.6	60	10,000 lb @ 110 PSI
24R20.5	XL	PR16	Tbls	54.8	24.6	23.8	384	18.00	251.3	13.6	20.5	40	15,435 lb @ 80 PSI
24R21	XL	PR16	Tbls	54.8	24.7	23.0	388	18.00 DC	263.8	14.2	20.9	40	15,435 lb @ 80 PSI
13R22.5	XL	18	Tbls	44.5	20.6	11.7	468	**9.0**	101.8	12.1	9.1	65	8,268 lb @ 125 PSI
12.00R24	XL	18	TT	48.3	22.4	11.6	430	**8.5**	107.4	13.2	8.8	65	8,820 lb @ 110 PSI

* Also available in XS
** Pilot
Measuring Rim in Bold Type

and the speeds are low. In this case, an on-board compressor would be required to reinflate the tires.

AM General has developed a central tire inflation system (CTIS) for use on the M923 5-ton Army truck. This system allows complete control of the tire inflation pressure from the driver's seat while the vehicle is moving.

7.1.3 6K VRRTFLT

The individual tire load for the 6K VRRTFLT will likely be about 5000 lbs., unloaded, and 7000 lbs., loaded, after it has been upgraded for 45 mph operation.

The current tire size for the Gradall 534B is 13.00-24-12 PR. The ML version of this tire is rated to 50 mph for 50 miles in a 1 1/2 hour period as shown in Table 15. The above loads are acceptable for inflation pressure in the 50-85 psi range.

Another candidate is the 14.00 R24 crane tire shown in Table 24 which has an ample load rating at 45 mph. The 12.00 R24 XL all-terrain tire shown in Table 25 also appears to be a viable candidate at highway speeds.

Thus, it appears that an acceptable tire should be available for this vehicle.

7.1.4 10K RTFLT

The maximum individual tire load for the 10K RTFLT will likely be about 15,000 lbs. loaded and unloaded, after it has been upgraded to 45 mph operation.

The current tire size for the M10A is 20.5 x 25 - 16PR inflated to 50 psi. No equivalent was found for these tires among those rated at high speed. None of the ML service tires can provide sufficient load capacity.

Only the 12.00 R20X crane tires shown in Table 23 can supply this load capacity and inflation pressure must be above 110 psi.

In the XL series of Table 25, the 24R 20.5 XL can supply this load capacity at 80 psi, but the loaded radius will be smaller.

For tires of the same nominal diameter, the Michelin 18.00 R25 XS and 21.00 R25 XS tires can provide sufficient load capacity. These are so-called sand tires and it is not known whether they will prove rugged enough for fork-lift operations in hard ground and rocky areas. The only speed information is that the maximum recommended speed on a road surface is 40 mph and on a track, 30 mph.

Thus, it is not clear from the information obtained from the tire manufacturers whether a tire is commercially available for the 10K RTFLT which can satisfy the two requirements:

- provide sufficient strength and ruggedness for rough-terrain fork-lift operations; and

- provide 45 mph speed capability for reasonable periods of operation.

It appears that high speed testing of candidate tires known to satisfy the ruggedness criterion will be required to determine their high speed capability.

7.2 DRIVELINE COMPONENTS

The general requirements for the driveline components were established in Section 6.4. These are:

- At a wheel speed of 45 mph and the vehicle unloaded,

  - the input shaft speed to the drive axles should be kept at or below 3500 rpm.

  - the torque delivered to the drive wheels must be capable of maintaining 45 mph on a specified grade (e.g., 2% or 5%)

- At a wheel speed of 2 mph and with rated forklift load,
  - the torque delivered to the drive wheels must be capable of climbing a 45% grade assuming that the wheels do not slip.

Gear ratios in the transmission between these limiting conditions would determine the speed ranges provided by each gear selection. If one were designing a high production vehicle such as an agricultural tractor, one would tailor these gear ratios to provide, as much as possible, the desired speeds in each range. For this type of vehicle, it is conventional to work within the confines of available components.

As part of this study, manufacturers of axles and transmissions were contacted and asked for recommendations in the light of the above general requirements and the existing components in the three vehicles of interest. Several combinations of components were examined for feasibility, especially for the 10K RTFLT which presents the major problems due to its required torque levels for the gradeability specification.

Combinations of driveline components that appear feasible for each vehicle are presented in the following subsections. The torque requirements used are those summarized in Tables 11 through 13 of Section 6.4. The total torque requirement was used for the 6K VR RTFLT so this vehicle is assumed to change from the asymmetric arrangement of the Gradall 534B with hydrostatic rear wheel drive to a symmetric arrangement similar to the other vehicles.

The relationship to the steering system and the possible requirement to go to Ackerman steering for all of the vehicles is recognized by examining and citing available steering axles which have equivalent drive characteristics.

We should point out that no attempt has been made to deal with detailed geometrical constraints for the components. This would have required information which we did not have and a level of effort beyond the scope of the project. To a degree, a vehicle, especially its frame, must be designed around its major components. To cut and patch in replacement components which may be larger and have different shape characteristics may not be practical.

However, feasibility questions clearly belong to the larger picture. We have assumed that feasible driveline components will be accommodated by performing the detailed layout design work and structural changes that are needed to fit them in and mount them.

7.2.1 4K RTFLT

The torque requirements for this vehicle were given in Table 11. The torque requirements for the upgraded vehicle assumed some weight penalty for upgrading the drive components and the engine.

Of the three vehicles, this vehicle has the simplest drivetrain to upgrade to 45 mph because the axles are single-stage reduction axles which currently operate with a very low input speed, about 1150 rpm at 20 mph. Thus, the speed of the axle only increases to about 2800 rpm at 45 mph and the same axle can be used to meet this requirement. Since it was also found to be capable of the torque required at 2 mph, the Rockwell axle can also be used on the upgraded vehicle.

To get the higher speed, Clark Equipment Co. recommends replacing their current M4K transmission with a six speed transmission with an overdrive range for high speed operation. A lock-up torque converter is integral with this transmission. Clark also recommends replacement of the 55 hp JI Case engine with a Cummins 120 hp engine. The original drivetrain is compared with the upgraded version in Table 26.

The drivetrain speeds for the upgraded version are shown in Table 27. For a 5% grade, the torque requirement shown in Table 11 for an unloaded vehicle is 1272 ft. lbs. which suggests that the 120 hp engine would not be able to hold speed on a 5% grade. The 2% grade, however, requires a torque of 728 ft. lbs. which translates into an engine torque of 161 ft. lbs. At 2350 rpm, this is a power requirement of 72 hp. Allowing a typical power

Table 26

Comparison of the Existing and Upgraded Drivetrain for the 4K RTFLT

Component	Existing M4K		Upgraded Version	
Wheel/tire	15 x 19.5- 8PR		Same Size	
Rolling radius	18.2"			
Axle	Rockwell		Same	
	D-140-FSH x 18			
Final ratio	6.80:1			
Transmission	Clark		Clark	
	11.2 HR 18340		12.6 HR 18654	
Ratio	FWD	REV	FWD	REV
1st	10.81	10.81	7.03	7.03
2nd	4.73	-	4.90	-
3rd	1.58	-	3.57	3.57
4th	-	-	2.49	-
5th	-	-	1.19	1.19
6th	-	-	0.83	-
Torque Converter	Clark		Clark	
	11.2 integral		12.6 integral	
Stall ratio	2.6:1			
Automatic/manual lock up	No		Yes	
Engine	Case		Cummins	
	G207D		6B5.9 4178A	
Horsepower	55 @ 2200 rpm		120 @ 2800 rpm	
Torque	131.3 ft. lbs.		225.1 ft. lbs.	

Table 27

Drivetrain Speeds for the Upgraded 4K RTFLT

Wheel Speed MPH	Axle Speed RPM	Driveshaft Speed RPM	Engine Speed RPM
45	416.4	2831.7	2350.3
2	18.5	125.9	884.7

requirement to overcome wind resistance at 45 mph of 28 hp still totals to only 100 hp, within the capabilities of a 120 hp engine. Thus, this version should be capable of holding speed on a 2% grade.

At 2 mph and 45% grade, the loaded vehicle requires 10,443 ft. lbs. at the wheels or 273 ft. lbs. at the engine which should be available at 2350 rpm. The total power required is 46 hp. At this speed, wind resistance would add very little power requirement, probably about 2 hp.

7.2.2 6K VRRTFLT

The torque requirements for this vehicle were given in Table 12. The torque requirements for the upgraded vehicle again assumed some additional weight penalty for upgrading the drive components including a larger engine.

The existing Gradall 534B has a conventional front axle and a hydrostatic drive for the rear wheels. The front axle is a two stage axle including both differential and planetary final drive reductions. In arriving at an upgraded version of this vehicle, we assumed that the hydrostatic drive will be replaced with a conventional axle identical with the one selected for the front wheels. The transmission then supplies power to both of these axles. Since this vehicle has a two-stage axle, the input drive shaft speed at a road speed of 18 mph is about 2500 rpm. Thus, increase of the road speed to 45 mph requires a reduction in the overall axle ratio to keep the drive shaft speed in the 3000 rpm range. To minimize this reduction, a transmission having an overspeed characteristic in the top gear range is desirable. Finally, an engine with considerably more power is required both for the power required at 45 mph and the torque required at 2 mph.

One version of this upgraded drivetrain is shown in comparison with the existing Gradall 534B (front axle) in Table 28.

Table 28

Comparison of the Existing Gradall 534B with an Upgraded Drivetrain for the 6K VR RTFLT

Component	Existing Gradall 534B (front axle)		Upgraded Version (both axles)	
Wheel/tire	13 x 24 - 8PR, G3		Same size	
Rolling radius	24.1"			
Axle	SOMA 12 MR/F		Clark (13000 Series)	
Final ratio	19.68 Diff. ratio = 4.62 Plan. ratio = 4.26		9.48	
Transmission	Clark		Clark 13.5 HR 32654	
Ratio	FWD	REV	FWD	REV
1st	6.17	6.17	6.45	6.45
2nd			4.43	-
3rd	1.00	1.00	2.81	2.81
4th			1.93	-
5th			1.00	1.00
6th			0.69	-
Torque converter	Clark		Clark 13.5 integral	
Automatic/manual lock up	?		Yes	
Engine	Waukesha VDR 220S		GM 6V 53T	
Horsepower	90 BHP @ 2600 rpm		225 BHP @ 2500 rpm	
Torque	182 ft. lbs.		473 ft. lbs.	

The drivetrain speeds for the upgraded version are shown in Table 29. The unloaded wheel torques from Table 12 for 2% and 5% grades are 1203 ft. lbs. and 2406 ft. lbs., respectively. These translate into engine torques of 230 ft. lbs. and 460 ft. lbs., respectively. The corresponding power requirements are 90 and 180 hp. Adding an expected wind resistance requirement of 28 hp at 45 mph gives total power requirements of 118 hp and 208 hp for the 2% and 5% grades. Thus, the GM 225 hp engine shown in Table 28 should enable the vehicle to hold speed on a 5% grade at 45 mph.

At 2 mph and 45% grade, the loaded vehicle requires 21,948 ft. lbs. at the wheels or 449 ft. lbs. at the engine which also should be within the capability of the GM engine. The total power requirement at this speed, allowing 2 hp for wind resistance, is 75 hp.

7.2.3 10K RTFLT

The torque requirements for this vehicle were given in Table 13. Assuming additional weight for the upgraded vehicle leads to a maximum wheel torque requirement at 2 mph for a 45% grade of 54,849 ft. lbs.

Because the existing vehicle uses an axle with an overall ratio of 24.05, the axle input speed is 2823 rpm at the maximum wheel speed of 22 mph. If this is increased to 45 mph, the axle input speed would increase to 5775 rpm which is unacceptable for available axles. To reduce this to our criterion of 3500 rpm requires dropping the overall axle ratio to a maximum of 14.57. Several commercially available axles were found in the correct axle load range which have available ratios down to and below this maximum. For the drivetrain option investigated further, a Rockwell axle having an overall ratio of 12.11 was selected as a prototype.

The next problem that occurs with this drivetrain results from the relatively low ratio chosen on the existing M10A for the International S700 transmission. This ratio of 4.322 in first gear range would result in a required engine torque of about 1300 ft. lbs. for the 45% grade even with the Rockwell axle. This very high torque level is normally found only on engines rated in the 450 to 475 hp range. Thus, it is desirable to reduce

Table 29

Drivetrain Speeds for the Upgraded 6K VR RTFLT

Wheel Speed MPH	Axle Speed RPM	Driveshaft Speed RPM	Engine Speed RPM
45	314.4	2981	2057
2	14	132	854

this torque level. This can be done by selecting a transmission which has a higher ratio in first gear, allowing a higher engine speed and lower engine torque at the 2 mph wheel speed.

The driveline upgrade shown in Table 30 uses a Twin-Disc powershift transmission which increases the ratio in first speed to 5.96.

The driveline speeds for the upgraded version are shown in Table 31. The unloaded wheel torques from Table 13 for 2% and 5% grades are 3151 and 6404 ft. lbs., respectively. The corresponding power requirements are 248 hp and 465 hp, adding an estimated 35 hp to overcome wind resistance. This shows that the engine will have to be upgraded to maintain 45 mph on a grade. It is likely, however, that it will prove desirable to specify the 45 mph on the lower grade rather than incur the penalties for a 5% grade.

At 2 mph and 45% grade, the loaded vehicle requires 950 ft. lbs. at the engine. This is feasible but would require a fairly large engine, equivalent to the Caterpillar 3406 series which are rated between 280 and 375 hp.

If the Clark 34640 6-speed powershift transmission were substituted for the Twin-Disc unit, the lowest gear ratio could be increased to 7.15, resulting in a significant reduction in engine torque on a 45% grade. This would likely allow the use of a smaller engine. However, the Clark 34000 series transmissions will not be available for at least 18 months according to Clark.

The ZF Model 4WG 65 II gearbox would allow a moderate increase in gear ratio to 6.3 which might allow a slightly smaller engine.

7.2.4 Steering Axles

The possibility has been raised in the discussion of handling problems that it may be desirable to go to rigid-frame four wheel steering vehicles to replace the current articulated machines. Also, it is likely that the 6K VR RTFLT will adopt a more conventional four wheel steering system for the

Table 30

Comparison of the Existing Driveline with an Upgraded Version for the 10K RTFLT

Component	Existing M10A	Upgraded Version
Wheel/tire	20.5 x 25 - Ply L-3	Same
Rolling radius	26.6"	
Axle	IH	Rockwell
	FR-65B	PRC 1756
Ratios	24.05	12.11
	(5.2 planetary-4.625 differential)	
Transmission	IH	Twin Disc
	S700	44-1133
1st	4.322	5.96
2nd	2.144	3.03
3rd	0.777	1.51
4th		0.77
5th		
6th		
7th		
Torque converter	Single stage, single phase	Integral
Automatic/manual lock up		Yes
Engine	IH	Caterpillar
	DT466	3406 series
HP	200 @ 2500 rpm	
Torque	420 ft. lbs.	

Table 31

Drivetrain Speeds for the Upgraded 10K RTFLT

Wheel Speed MPH	Axle Speed RPM	Driveshaft Speed RPM	Engine Speed RPM
45	284.3	3443	2651
2	12.63	153	912

45 mph version. Thus, the availability of equivalent steering axles for each of the upgraded versions discussed in the preceding section becomes an important question.

In general, it can be stated that the axle manufacturers provide an equivalent or near-equivalent steering axle for each rigid axle.

For example, the current Rockwell D-140-FSH x 18 axle used on the M4K would be retained in the upgraded version of Table 26. This is a single reduction truck axle. There is no direct equivalent steering axle. However, the FDS-1600 series steering axles provide slightly larger load capacity and similar axle ratios.

However, in the case of the double reduction planetary axles used on the larger machines, the available steering axle equivalents employ a vertical kingpin design in most cases. It was pointed out in Section 6.5 that the vertical kingpin design leads to a large positive scrub radius which, in turn, produces destabilizing steering moments during braking or when the wheels encounter a bump. At high speed when handling stability is likely to be marginal, at best, such behavior is not desirable. Thus, if Ackerman steering is selected for these larger machines, the steering axle should employ a non-vertical kingpin axis which provides a small positive or negative scrub radius.

None of the U.S. axle manufacturers surveyed provide a tilted kingpin axle. ZF and SOMA appear to provide a full line of steering axles with tilted kingpin axis. However, the SOMA axis is reportedly only 8° off-vertical. Even taking the typical 2° of camber into account, this would likely leave a significant positive scrub radius.

ZF states that their steering axles provide negative scrub radius. Thus, tentatively, it may be concluded that the ZF axles are the most suitable available for high speed operation. Parenthetically, it may be noted that ZF axles are used on the Zettelmeyer ZL75C. An illustration of a ZF axle with titled kingpin axis is shown in Figure 30.

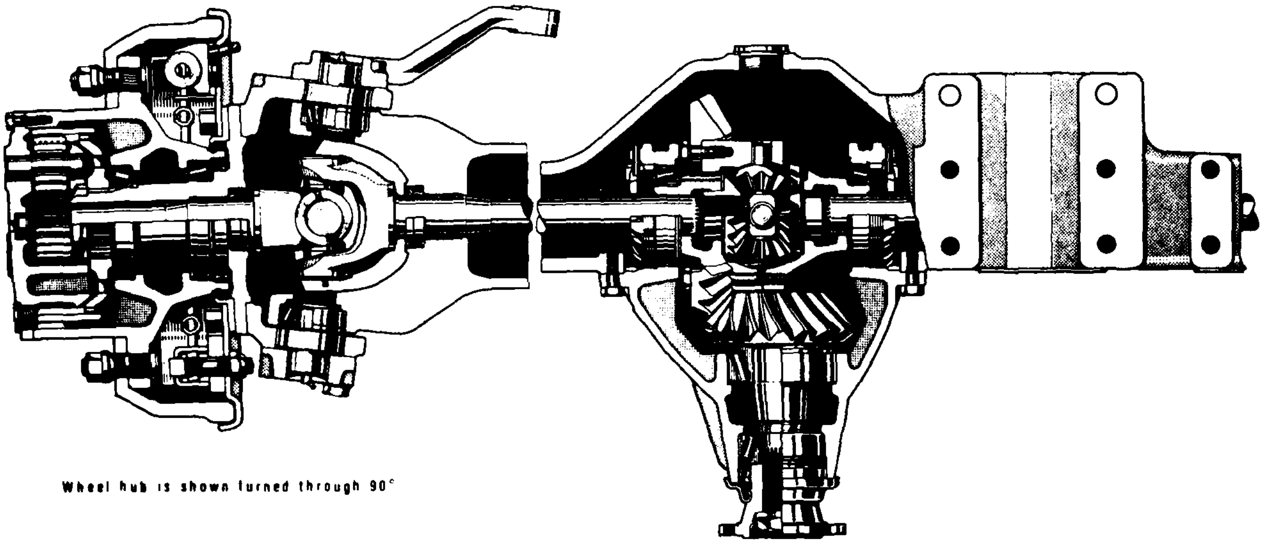

Wheel hub is shown turned through 90°

FIGURE 30 ZF PLANETARY STEERING AXLE

7.3 HYDRAULIC POWER STEERING COMPONENTS

Commercial components are available for implementing any of the basic steering systems discussed in Section 6.3 A number of manufacturers supply components but the types of interest here are described in Appendix D under the heading, ZF Steering Gear, for convenience since this manufacturer supplied a complete line.

As noted in Section 6.3.1, the gain or steering force available can be varied by the selection of steering power cylinders and pumps. However, the choice of steering gear which contains the control valve will depend upon the vehicle configuration.

For cases where a direct mechanical link is possible between the steering gear and the steering knuckle or articulation pivot, a semi-integral power steering gear, either single or dual circuit, would be used. These units are recirculating ball and nut steering gears, similar to those used on passenger cars, except that the power cylinder is not integral to the steering gear as it is in a lighter duty unit. Instead, the power cylinders are separately mounted at the steering joint and are connected to the integral control valve by hydraulic lines. The hydraulic steering force parallels the direct mechanical link which serves as an emergency backup and also provides driver feedback.

The dual-circuit design provides extra safety for larger machines where manual steering alone would not be capable of steering the vehicle if a hydraulic circuit failed. In this case, two independent valves are provided in the steering gear which control two completely independent power cylinders. One of these circuits is usually supplied by an engine-driven pump and the other by a wheel-driven pump so that power steering is preserved even if the engine fails.

For vehicles where no mechanical linkage can be provided between the steering gear and the steered joint, hydrostatic steering units can be used. They are not recommended for applications exceeding about 30 mph, but this limit appears to be based upon operational or statutory, rather than technical considerations. The steering box meters a volume of pressurized oil to the power cylinder which depends upon the steering wheel angle. Both engine-driven and wheel-driven supply pumps are typically used for emergency backup in case of cylinder failure.

In addition to the basic steering gear with integral control valves, steering component manufacturers also supply a wide variety of pumps and valves to tailor the system to individual needs.

A variety of mechanical components are also available for the linkage between the steering wheel and steering gear. Of particular interest for a dual-position steering arrangement of the type discussed in Section 6.3.2, intermediate steering gears are available which allow several steering columns to be connected to one steering box.

8. CONCLUSIONS

The major conclusions reached as a result of this study are as follows:

(a) Upgrading the three sizes of Army RTFLT's to 45 mph so that they can be self-deployable appears generally feasible on the basis of the information obtained in this study. However, limitations may be imposed by handling characteristics and tires, especially on the larger size units. These problem areas could not be fully resolved with available information.

(b) All three RTFLT's will require the addition of a suspension system for high speed operation. The most readily adaptable design is a hydropneumatic system which can be implemented with available hydraulic components and gas-over-hydraulic accumulators. The vehicle frames will require modification to provide clearance for axle motion and to mount supporting arms.

(c) Handling characteristics cannot be fully resolved without an extensive analysis and high speed testing. It is clear that handling problems can occur with the articulated vehicles and the 10K size, at least, has marginal static stability. Ultimately, it may prove necessary to lock up the articulated joint and provide auxiliary Ackerman front-wheel steering for 45 mph. Alternatively, all three machines could be redesigned as four-wheel coordinated steered machines with front-wheel steering for highway or high speed travel.

(d) Components appear to be generally available to implement the various steering system options. However, there is a limitation on available two-stage planetary steering axles which are suitable, from a handling point of view, at 45 mph.

(e) Significant driveline modifications are required on all three vehicles to achieve 45 mph operation. Wider range powershift transmissions are required and lock-up torque converters are needed for the high speed operation. The overall axle ratio must be reduced for the larger machines. Significantly higher power engines are required in all three cases to provide enough power for high-speed operation and, in the case of the 10K machine, enough torque for low-speed gradeability.

(f) Tires, in equivalent sizes, appear to be available for the 4K and 6K machines for which there is some data on high speed capabilities. However, it is possible that some limitation may be placed on the distance or period of time allowable at 45 mph for tires which are suitable for rough terrain fork lift operations. Also, adjustment of the inflation pressure to separate levels for 45 mph road operation and rough terrain operation may be required.

(g) It is not clear, from the information available from tire manufacturers, whether there is a commercially available tire for the 10K machine that can provide sufficient strength and 45 mph capability for reasonable periods of operation.

(h) Ultimately, testing will be required to establish the operating limitations at 45 mph on available tires. This data does not appear to be available at the present.

9. RECOMMENDATIONS

It is clear from the results of this study that the next step of the development program leading to a self-deployable rough terrain forklift truck must involve a combination of testing and design analysis.

Three areas of experimental evaluation are of major importance.

- Experimental testing and optimization of a suspension system,
- Experimental evaluation of handling characteristics, especially of the articulated vehicles,
- Tire testing under high speed conditions.

The first two of these require a vehicle test bed. Thus, it is recommended that a development test machine be designed and built for this purpose. It would appear that two approaches could be taken to obtain such a test bed:

- The first approach would be to select a machine similar to the Army RTFLT's which has a suspension system and can be upgraded to 45 mph. The only vehicle located which meets these criteria is the Zettelmeyer ZL75C.
- The second approach would be to modify either the M4K or the M10A to add a suspension system and upgrade the drive components for 45 mph operation. This will require a detailed layout design to determine whether suitable components and subassemblies can be added to the existing vehicle. The M10A size is expected to present the most serious handling problems and, thus, would be preferable as the test machine.

Tire testing will be required to determine the limitations on 45 mph operation placed on the machines by the tire heat buildup. It is recommended that this problem be approached in the following way:

- The optimum available tire should be selected for each vehicle in consultation with each of the major tire suppliers.

- These tires should be tested on a tire test machine under appropriate combinations of load and inflation pressure. Heat buildup is monitored during this type of testing by means of thermocouples in the tires.

- Several independent testing laboratories have the capability for this type of testing.

If detailed analytical modeling and dynamic analysis is required to develop appropriate vehicle handling characteristics, it is likely that tire side force versus slip angle characteristics will be required for the tires. This will also require special tire tests since this data is not now available for off-road vehicle tires.

Bibliography

Bibliography

1. Truck, Lift, Fork, Diesel-Engine-Driven: Pneumatic Tired, Rough Terrain; 4000-Pound Capacity at 24-Inch Load Center, Military Specification, MIL-T-52941, 29 November 1977.

2. Truck, Lift, Fork, Diesel-Engine-Driven: Pneumatic Tired, Rough Terrain; 10000-Pound Capacity at 48-Inch Load Center, Military Specification, MIL-T-52843C, 1 May 1985.

3. Truck, Lift, Fork, Variable Reach,Diesel-Engine-Driven, Pneumatic Tired, Rough Terrain; 6000-Pound Capacity at 24-Inch Load Center, Military Specification, MIL-T-53038 (ME), 21 March 1984.

4. Test Report on a Zettelmeyer ZD 3000 Dozer for Terex, Ltd., Report T. 340, Military Vehicles and Engineering Establishment, Christchurch, England, February 1982.

5. Holm, I. C., Articulated, Wheeled Off-the-Road Vehicles, Journal of Terramechanics, Vol. 7, No. 1, 1970.

6. Janowski, W. R., Arctic Operations with the Twister Testbed, SAE Paper 710715, September 1971.

7. Watson, T. H., Heavy Duty Truck Tandem Suspension for On/Off Highway Applications, SAE Paper 740306, March 1974.

8. Claar, P. W., Buchele, W. F., and Sheth, P. N., Off-Road Vehicle Ride: Review of Concepts and Design Evaluation with Computer Simulation, SAE Paper 801023, September 1980.

9. Claar, P. W. et al., Agricultural Tractor Chassis Suspension System for Improved Ride Comfort, SAE Paper 801020, September 1980.

10. Young, R. E., and Suggs, C. W., An Active Seat Suspension System for Isolation of Roll and Pitch in Off-Road Vehicles, ASAE Paper 73-156, June 1973.

11. Hall, G. O., Providing Ride Comfort for the Operator of Off-Highway Vehicles, SAE Paper 690567, September 1969.

12. Spangler, E. B., and Kelly, W. J., GMR Road Profilometer - A Method for Measuring Road Profile, National Research Council paper on Highway Research, 1965.

13. Walker, R. S., and Hudson, W. R., The Use of Spectral Estimates for Pavement Characterization, Center for Highway Research, University of Texas at Austin, August 1973.

14. Wambold, J. C., The Measurement and Data Analysis Used to Evaluate Highway Roughness, Wear, Vol. 57, 1979.

Bibliography (Continued)

15. Wambold, J. C. et al., State of the Art of Measurement and Analysis of Road Roughness, The Pennsylvania State University, May 1981.

16. Crolla, D. A., and Hales, F. D., The Lateral Stability of Tractor and Trailer Combinations, Journal of Terramechanics, Vol. 16, No. 1, 1979.

17. Crolla, D. A., Off-Road Vehicle Dynamics, Vehicle System Dynamics, Vol. 10, 1981.

18. Crolla, D. A., and Horton, D. N. L., The Steering Behavior of Articulated Body Steer Vehicles, Inst. of Mech. Eng. Paper C123/83, 1983.

19. Horton, D. N. L., and Crolla, D. A., Designing Off-Road Vehicles With Good Ride Behavior, paper presented at the 8th International Conf. of the Int. Soc. for Terrain Vehicle Systems, Cambridge, U. K., 1984.

20. Crolla, D. A., and MacLaurin, E. B., Theoretical and Practical Aspects of the Ride Dynamics of Off-Road Vehicles - Part 1, Journal of Terramechanics, Vol. 22, No. 1, 1985.

21. Crolla, D. A., and Horton, D. N. L., Factors Affecting the Dynamic Behavior of Higher Speed Agricultural Vehicles, Journal of Agricultural Engineering Research, Vol. 30, 1984.

22. Captain, K. M., Boghani, A. B., and Wormley, D. N.; Analytical Tire Models for Dynamic Vehicle Simulation; The International Journal of Vehicle Dynamics; March, 1979.

23. Clark, S. K., Editor, Mechanics of Pneumatic Tires, U. S. Department of Transportation publication.

24. 862 Scraper Suspended Axle, John Deere Product Information Bulletin TC-102, March, 1985.

25. 1985 Year Book, The Tire and Rim Association, Inc., Akron, Ohio, 1985.

26. Michelin Truck, Industrial & Off-The-Road Tire Data Book, 1985-86, Michelin Tire Corp., Greenville, S.C., 1985.

Appendix A

Computer Program "TRUCK"
for
Simulation of Vertical and Pitch Motion

```
      PROGRAM TRUCK
      DIMENSION STATE(8),DERY(8)
      COMMON /PARAM/SPEED,WAVE,AMPL,AMV,AIV,AMW1,AMW2
     1              ,AL,AL1,AL2,AH,AK1,AK2,AB1,AB2,AKT
     2              ,ABT,XCG,XSTEP,YLIM,TDIF
      COMMON /VAR/Y0,YIN1,YIN2,YTIN1,YTIN2,THETA,YW1,YW2
     1            ,ILIFT1,ILIFT2,FV1,FV2,FX1,FX2
      COMMON /DYN/T,TSTEP,STATE,DERY,STIME,FTIME,NSYS,ISTIF
      COMMON /CONST/PI,G,PATH
C     OPEN(4,FILE='TRUCK.OUT',status='NEW')
      OPEN(5,FILE='TRUCK.DBG',status='NEW')
      OPEN(6,FILE='TRUCK.PRN',status='NEW')
      OPEN(7,FILE='TRUCK.DAT',status='OLD')
      WRITE(6,930)
      PATH = 0
      IF (PATH.EQ.1) WRITE(5,999)
C     AMV    = MASS OF VEHICLE (KG)
C     AIV    = MOMENT OF INERTIA (KG*M*M)
C     AMW1   = MASS OF FRONT UNSP. MASS (EACH) (KG)
C     AMW2   = MASS OF REAR UNSP. MASS (EACH) (KG)
C     AL     = FOOT PRINT LENGTH (M)
C     AL1    = FRONT SUSPENSION FROM CG (M)
C     AL2    = REAR SUSPENSION FROM CG (M)
C     AH     = HT OF CG FROM SUSP. CONT. (M)
C     AK1    = STIFFNESS OF FRONT SUSPENSION (EACH) (N/M)
C     AK2    = STIFFNESS OF REAR SUSPENSION (EACH) (N/M)
C     AB1    = DAMPING OF FRONT SUSPENSION (EACH) (N*S/M)
C     AB2    = DAMPING OF REAR SUSPENSION (EACH) (N*S/M)
C     AKT    = TIRE STIFFNESS (N/M)
C     ABT    = TIRE DAMPING (N*S/M)
C     YLIM   = LIMIT OF TIRE DEFLECTION
C     TDIF   = STIFFNESS MULTIPLIER FOR TIRE STOP
C     ISTIF  = 1, FOR INFINITELY STIFF SUSPENSIONS (NO NEED TO CHANGE
C              AK1, AK2 ETC.)
C
        READ(7,*) SPEED
        READ(7,*) WAVE
        READ(7,*) AMPL
        READ(7,*)
        READ(7,*) AMV
        READ(7,*) AIV
        READ(7,*) AMW1
        READ(7,*) AMW2
        READ(7,*) AL
        READ(7,*) AL1
        READ(7,*) AL2
        READ(7,*) AH
        READ(7,*) AK1
        READ(7,*) AK2
        READ(7,*) AB1
        READ(7,*) AB2
        READ(7,*) AKT
        READ(7,*) ABT
        READ(7,*) YLIM
        READ(7,*) TDIF
      READ(7,*) NSYS
      READ(7,*) ISTIF
      READ(7,*) XCG
      READ(7,*) STIME
      READ(7,*) FTIME
C
      XSTEP = WAVE/20.0
C
C
      READ(7,*)
      READ(7,*) ITIMER
      READ(7,*)
      IF( ITIMER .EQ. 0 )THEN
         TSTEP = XSTEP/SPEED
      ELSEIF( ITIMER .EQ. 1 )THEN
         READ(7,*) TSTEP
      ELSE
         WRITE(*,*)
         WRITE(*,*)
         WRITE(*,*)
         WRITE(*,*) '!!!!!! ITIMER can only equal 0 or 1 !!!!!!'
         WRITE(*,*)
         WRITE(*,*) 'I have taken it equal to 0 since you made a ',
     1              'mistake '
         TSTEP = XSTEP/SPEED
         WRITE(*,*)
         WRITE(*,*)
         WRITE(*,*) 'Because of this...............TSTEP = ',TSTEP
         WRITE(*,*)
      ENDIF
C
C
C
      IF (ISTIF.EQ.1) TSTEP = TSTEP/5
      PSTEP = 0.1
      G     = 9.8
      PI    = 3.14159
      T     = STIME
C
      IF (ISTIF.EQ.0) GOTO 5
        AMV = AMV+2.0*(AMW1+AMW2)
        AIV = AIV+2.0*(AMW1*AL1*AL1+AMW2*AL2*AL2)
        AMW1 = 0.0
        AMW2 = 0.0
        NSYS = 4
5     CONTINUE
C
      YIN1   = AMV*G*AL2/(AL1+AL2)/2.0/AK1
      YIN2   = AMV*G*AL1/(AL1+AL2)/2.0/AK2
      YTIN1  = (YIN1*AK1+AMW1*G)/AKT
      YTIN2  = (YIN2*AK2+AMW2*G)/AKT
C
      DO 10 I=1,NSYS
        STATE(I)  = 0.0
        DERY(I)   = 0.0
```

```
10          CONTINUE
C
        CALL EQSIM
C
20      CONTINUE
c        WRITE(4,900) T,XCG,Y0,THETA
c        WRITE(4,910) YW1,YW2,ILIFT1.ILIFT2
c        WRITE(4,920) FV1,FV2,FX1.FX2
        IF  (MOD(T,FSTEP).LT.TSTEP.AND.MOD(T,FSTEP).GE.0)
     1      WRITE(6,940) T.Y0,THETA,FV1,FV2,FX1,FX2
        CALL RKDIF
        XCG = XCG+SPEED*TSTEP
        IF(T.LE.FTIME) GOTO 20
C
900    FORMAT(2X,'T',6X,'= ',F8.4,2X,'XCG',4X,'= ',F8.4,2X,
     1         'Y0',5X,'= ',F8.4,2X,'THETA',2X,'= ',F8.4)
910    FORMAT(2X,'YW1',4X,'= ',F8.4,2X,'YW2',4X,'= ',F8.4,2X,
     1         'ILIFT1',1X,'= ',I8,2X,'ILIFT2',1X,'= ',I8)
920    FORMAT(2X,'FV1',4X,'= ',F8.2,2X,'FV2',4X,'= ',F8.2,2X,
     1         'FX1',4X,'= ',F8.2,2X,'FX2',4X,'= ',F8.2)
930    FORMAT(1X,'T',10X,'Y0',9X,'THETA',6X,'FV1',8X,'FV2',8X,'FX1',8X
     1         ,'FX2')
940    FORMAT(3(1X,F10.4),4(1X,F10.2))
999    FORMAT(2X,'NOW ENTERING MAIN PROGRAM')
       END
C
C
C                 *** RKDIF ***
C RUNGE-KUTTA 4TH ORDER INTEGRATION ROUTINE
C VARIABLES:
C      SY,Y0,Y1,Y2,H,PRT1,PRT2
C
       SUBROUTINE RKDIF
       DIMENSION SY(8),Y0(8),Y1(8),Y2(8),STATE(8),DERY(8)
       COMMON /DYN/T,TSTEP,STATE,DERY,STIME,FTIME,NSYS,ISTIF
       COMMON /CONST/PI,G,PATH
       IF (PATH.EQ.1) WRITE(5,999)
C
C         IF (DEBUG.EQ.1) WRITE(6,900)
          H=TSTEP/2.0
          NEW=0
C
          DO 10 I=1,NSYS
            SY(I)=STATE(I)
            Y0(I)=DERY(I)
            STATE(I)=H*DERY(I)+STATE(I)
10        CONTINUE
C
          T=T+H
          CALL EQSIM
C
          DO 20 I=1,NSYS
            Y1(I)=DERY(I)
            STATE(I)=SY(I)+H*DERY(I)
20        CONTINUE
```

```
C
        CALL EQSIM
C
        DO 30 I=1,NSYS
          Y2(I)=DERY(I)
          STATE(I)=SY(I)+TSTEP*DERY(I)
30      CONTINUE
C
        T=T+H
        CALL EQSIM
        H=H/3.0
C
        DO 40 I=1,NSYS
          PRT1=2.0*(Y1(I)+Y2(I))
          PRT2=YO(I)+DERY(I)
          STATE(I)=SY(I)+H*PRT1+H*PRT2
40      CONTINUE
C
        NEW = 1
        CALL EQSIM
C
        RETURN
999     FORMAT(2X,'ENTERING RKDIF'/)
      END
C
C
C              *** EQSIM ***
C EQUATION SIMULATION SUBROUTINE
C
      SUBROUTINE EQSIM
      DIMENSION STATE(8),DERY(8)
      COMMON /PARAM/SPEED,WAVE,AMPL,AMV,AIV,AMW1,AMW2
     1              ,AL,AL1,AL2,AH,AK1,AK2,AB1,AB2,AKT
     2              ,ABT,XCG,XSTEP,YLIM,TDIF
      COMMON /VAR/YO,YIN1,YIN2,YTIN1,YTIN2,THETA,YW1,YW2
     1             ,ILIFT1,ILIFT2,FV1,FV2,FX1,FX2
      COMMON /DYN/T,TSTEP,STATE,DERY,STIME,FTIME,NSYS,ISTIF
      COMMON /CONST/PI,G,PATH
      IF (PATH.EQ.1) WRITE(5,999)
        YO      = STATE(1)
        DYO     = STATE(2)
        THETA   = STATE(3)
        DTHETA  = STATE(4)
C
        IF (ISTIF.EQ.1) GOTO 20
          YW1     = STATE(5)
          DYW1    = STATE(6)
          YW2     = STATE(7)
          DYW2    = STATE(8)
20      CONTINUE
C
C SUSPENSION FORCES
        YL1     = YO+AL1*THETA
        YL2     = YO-AL2*THETA
        DY1     = DYO+AL1*DTHETA
        DY2     = DYO-AL2*DTHETA
C
        IF (ISTIF.EQ.0) GOTO 30
          YW1 = YL1
          YW2 = YL2
          DYW1 = DY1
          DYW2 = DY2
30      CONTINUE
C
        FK1     = AK1*(YW1-YL1+YIN1)
        FD1     = AB1*(DYW1-DY1)
        FY1     = FK1+FD1
        FK2     = AK2*(YW2-YL2+YIN2)
        FD2     = AB2*(DYW2-DY2)
        FY2     = FK2+FD2
C OBTAIN FV1,FV2,FX1,FX2 FROM THE TIRE MODEL
        X1 = XCG+AL1
        X2 = XCG-AL2
        CALL TIRE(YW1,DYW1,X1,YTIN1,FV1,FX1,ILIFT1)
        CALL TIRE(YW2,DYW2,X2,YTIN2,FV2,FX2,ILIFT2)
        IF (ISTIF.EQ.0) GOTO 40
          FY1 = FV1
          FY2 = FV2
40      CONTINUE
C
        DERY(1) = DYO
        DERY(2) = -G+2.0*(FY1+FY2)/AMV
        DERY(3) = DTHETA
        DERY(4) = 2.0*(-FY2*(AL2*COS(THETA)-AH*SIN(THETA))
     1                 +FX2*(AH*COS(THETA)+AL2*SIN(THETA))
     2                 +FY1*(AL1*COS(THETA)+AH*SIN(THETA))
     3                 +FX1*(-AL1*SIN(THETA)+AH*COS(THETA)))/AIV
C
        IF (ISTIF.EQ.1) GOTO 50
          DERY(5) = DYW1
          DERY(6) = -G+(FV1-FY1)/AMW1
          DERY(7) = DYW2
          DERY(8) = -G+(FV2-FY2)/AMW2
50      CONTINUE
C
        RETURN
999   FORMAT(2X,'NOW ENTERING EQSIM')
      END
C
C
C              *** TIRE ***
      SUBROUTINE TIRE (YW,DYW,X,YTIN,FV,FX,ILIFT)
      COMMON /PARAM/SPEED,WAVE,AMPL,AMV,AIV,AMW1,AMW2
     1              ,AL,AL1,AL2,AH,AK1,AK2,AB1,AB2,AKT
     2              ,ABT,XCG,XSTEP,YLIM,TDIF
      COMMON /CONST/PI,G,PATH
      IF (PATH.EQ.1) WRITE(5,999)
        ILIFT = 0
        YAV   = WAVE*AMPL*SIN(PI*AL/WAVE)*SIN(2.0*PI*X/WAVE)/PI/AL
        DYAV  = 2.0*AMPL*(SPEED/AL)*SIN(PI*AL/WAVE)*COS(2.0*PI*X/WAVE)
        YDIF  = YAV-YW+YTIN
        FVK   = AKT*YDIF
        FVB   = ABT*(DYAV-DYW)
        FV    = FVK+FVB
        Y1    = AMPL*SIN(2.0*PI*(X-(AL/2.0))/WAVE)
        Y2    = AMPL*SIN(2.0*PI*(X+(AL/2.0))/WAVE)
        AINT1 = (PI/WAVE)*(Y2*SQRT(AMPL*AMPL-Y2*Y2)
     1                     -Y1*SQRT(AMPL*AMPL-Y1*Y1)
     2                     +AMPL*AMPL*2.0*AL/WAVE)
        FX    = (Y2-Y1)*(DYW*ABT+(YW-YTIN)*AKT)/AL
     1          -AKT*(Y2*Y2-Y1*Y1)/2.0/AL
     2          -SPEED*(ABT/AL)*AINT1
        IF (FV.LE.0.0) THEN
          FX    = 0.0
          FV    = 0.0
          ILIFT = 1
          ENDIF
        IF (YDIF.GE.YLIM) THEN
          FEXT = (TDIF-1.0)*AKT*(YDIF-YLIM)
          FV = FV + FEXT
          FX = FX + FEXT*(Y1-Y2)/AL
          ENDIF
        RETURN
999   FORMAT(2X,'NOW ENTERING TIRE')
      END
```

```
        20.12       SPEED
        4.31        WAVE
        0.076       AMPL

        4354.6      AMV
        5915.6      AIV
        226.8       AMW1
        226.8       AMW2
        .09         AL
        1.26        AL1
        1.07        AL2
        .28         AH
        256639.     AK1
        256639.     AK2
        1253        AB1
        1253        AB2
        616704.     AKT
        441.5       ABT
        0.15        YLIM
        10.00       TDIF
        8           NSYS
        0           ISTIF
        0.0         XCG
        0.0         STIME
        10.0        FTIME
ITIMER = 1 to choose your own TSTEP, or else =0.
        1           ITIMER


       .0045        TSTEP
```

Appendix B

Analysis of Lateral Stability and Response of Articulated Fork-Lift Trucks

B-1 Equations of Motion

A schematic diagram of the articulated vehicle is shown in Figure B-1, where the centers of masses for the two halves of the body are defined. The tire forces of each body segment are shown as X_i along the axis and Y_i lateral to the axis.

The resultant velocities of the two body segments are,

$$V_1^2 = u_1^2 + v_1^2 \tag{1}$$

$$V_2^2 = u_2^2 + v_1^2 \tag{2}$$

The velocity relationships at the hinge joint can be written,

$$u_2 = u_1 \cos \theta - (v_1 - b_1 r_1) \sin \theta \tag{3}$$

$$v_2 = u_1 \sin \theta + (v_1 - b_1 r_1) \cos \theta \tag{4}$$

$$r_2 = r_1 - \dot{\theta} \tag{5}$$

Combining Eqs (1) through (5) gives

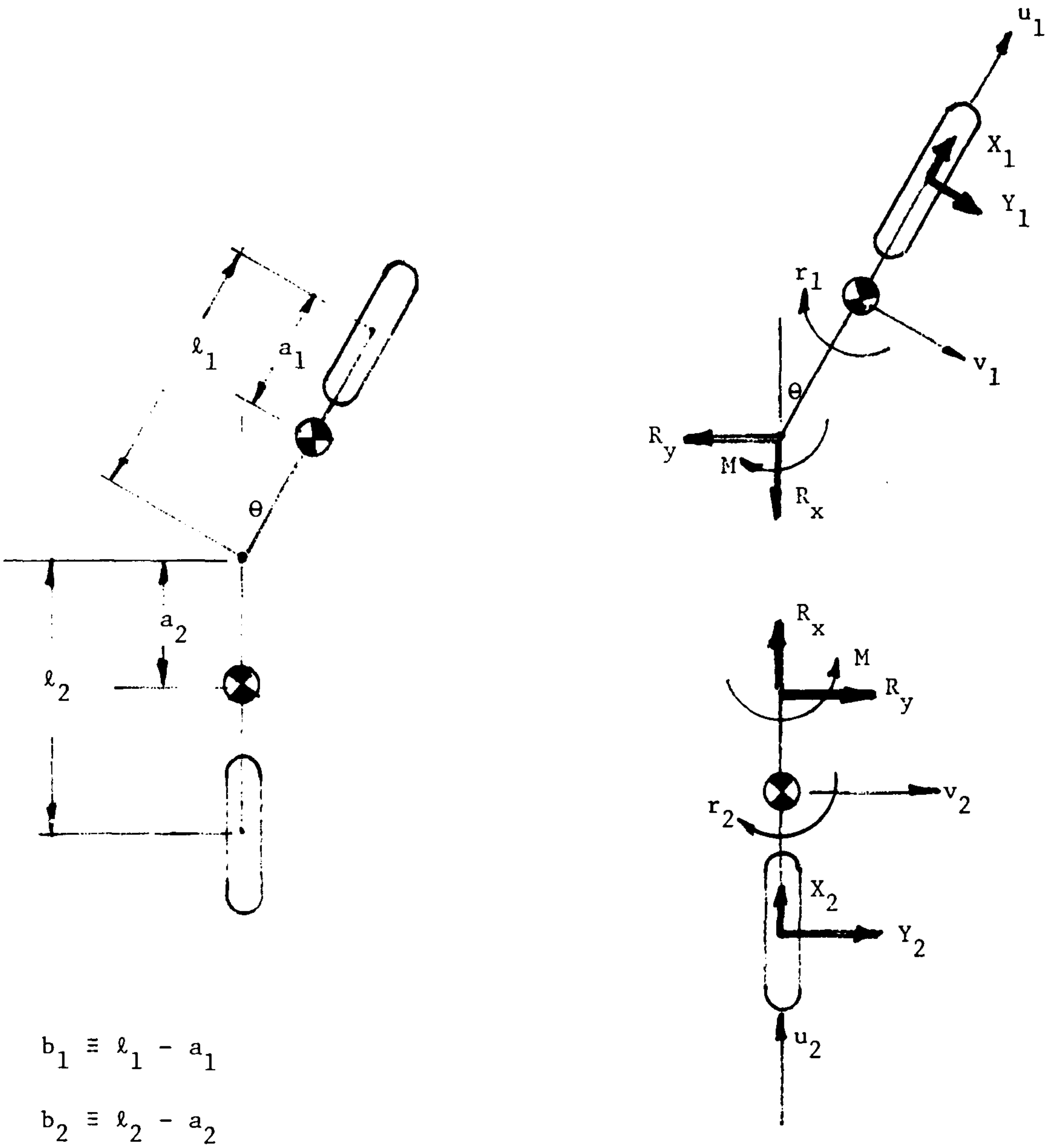
$$\begin{aligned} V_2^2 = u_2^2 + v_2^2 = u_1^2 + (v_1 - br_1)^2 \\ - 2a_2 r_2 [u_1 \sin \theta + (v_1 - b_1 r_1) \cos \theta] + a_2^2 r_2^2 \end{aligned} \tag{6}$$

The total kinetic energy in the system can be written as,

$$\begin{aligned} T = \tfrac{1}{2} m_1 (u_1^2 + v_1^2) + 1/2\, m_2 (u_2^2 + v_2^2) \\ + 1/2\, I_1 r_1^2 + 1/2\, I_2 r_2^2 \end{aligned} \tag{7}$$

Where m_i and I_i are the masses and moments of inertia of the two segments.

Substituting Eqs. (5) and (6) into (7) gives,


ℓ1
a1
θ
a2
ℓ2
u1
X1
Y1
r1
v1
θ
Ry
M
Rx
Rx
M
Ry
v2
r2
X2
Y2
u2

$b_1 \equiv \ell_1 - a_1$

$b_2 \equiv \ell_2 - a_2$

Figure B-1

Schematic Diagram of An Articulated Vehicle

$$T = 1/2\ m_1(u_1^2 + v_1^2) + 1/2\ m_2\ [u_1^2 + (v_1 - b_1 r_1)^2]$$

$$- m_2 a_2 r_2\ [u_1 \sin\theta + (v_1 - b_1 r_1) \cos\theta]$$

$$+ 1/2\ a_2^2 r_2^2 m_2 + 1/2\ I_1 r_1{}^2 + 1/2\ I_2\ (r - \dot{\theta})^2 \tag{8}$$

Differentiating T with respect to u_1 gives,

$$\frac{\partial T}{\partial u_1} = M\ u_1 - m_2 a_2\ (r_1 - \dot{\theta}) \sin\theta \tag{9}$$

where $M = m_1 + m_2$ (10)

Differentiating T with respect to v_1 gives,

$$\frac{\partial T}{\partial v_1} = M\ v_1 - m_2\ (b_1 + a_2 \cos\theta)\ r_1 + m_2 a_2 \dot{\theta}\ \cos\theta \tag{11}$$

Differentiating T with respect to r_1 can be shown to give,

$$\frac{\partial T}{\partial r_1} = J r_1 - m_2 (b_1 + a_2 \cos\theta)\ v_1$$

$$- m_2 a_2 u_1 \sin\theta - J_2 \dot{\theta} \tag{12}$$

where $J = J_1 + J_2$ (13)

and $J_1 = I_1 + m_2 b_1\ (b_1 + a_2 \cos\theta)$ (14)

$J_2 = I_2 + m_2 a_2\ (a_2 + b_1 \cos\theta)$ (15)

La Grange's equations can be written,

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) - \frac{\partial T}{\partial q_i} = Q_i \tag{16}$$

Since $\dot{q}_1 = u_1$

$\dot{q}_2 = v_1$

$\dot{q}_3 = r_1$

$$\frac{dT}{dq_i} = 0 \tag{17}$$

$$\therefore \frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) = Q_i \tag{18}$$

The external forces and moments are,

$$Q_1 = X_1 + X_2 \cos \theta + Y_2 \sin \theta \tag{19}$$

$$Q_2 = Y_1 + Y_2 \cos \theta - X_2 \sin \theta \tag{20}$$

$$Q_3 = a_1 Y_1 - (b_1 + \ell_2 \cos \theta)\, Y_2 + b_1 \sin \theta\, X_2 \tag{21}$$

Combining Eqs. (9), (11), (12), (18), (19), (20) and (21) gives,

$$\begin{aligned} M(\dot{u}_1 - v_1 r_1) - m_2 a_2 (\dot{r}_1 - \ddot{\theta}) \sin \theta - m_2 a_2 (r_1 - \dot{\theta})\dot{\theta} \cos \theta & \\ = X_1 + X_2 \cos \theta + Y_2 \sin \theta & \end{aligned} \tag{22}$$

$$\begin{aligned} M (\dot{v}_1 + u_1 r_1) - m_2 (b_1 + a_2 \cos \theta)\, \dot{r}_1 + m_2 a_2 r_1 \dot{\theta} \sin \theta & \\ + m_2 a_2 \ddot{\theta} \cos \theta - m_2 a_2 \dot{\theta} \sin \theta & \\ = Y_1 + Y_2 \cos \theta - X_2 \sin \theta & \end{aligned} \tag{23}$$

$$\begin{aligned} J \dot{r}_1 - m_2 (b_1 + a_2 \cos \theta)(\dot{v}_1 + u_1 r_1) - m_2 a_2 \sin \theta\, (\dot{u}_1 - v_1 r_1) & \\ + m_2 a_2\, v_1\, \dot{\theta} \sin \theta - m_2 a_2 u_1\, \dot{\theta} \cos \theta - J_2 \ddot{\theta} & \\ = a_1 Y_1 - (b_1 + \ell_2 \cos \theta)\, Y_2 + (b_1 \sin \theta) X_2 & \end{aligned} \tag{24}$$

Eqs. (22), (23), and (24) can be simplified by making the following assumptions:

(a) θ is a small angle so that

$$\cos\theta = 1$$

$$\sin\theta \approx 0$$

(b) the motion is "linear" so that the higher order velocity terms $v_1 r_1$, $r_1\dot{\theta}$, and $\dot{\theta}^2$ can be neglected.

(c) the axial velocity is constant so that $\dot{u}_1 = 0$ and $u_1 = U$

These reduce Eqs. (22), (23), and (24) to,

$$M(\dot{v}_1 + Ur_1) - m_2(b_1 + a_2)\dot{r}_1 + m_2 a_2 \ddot{\theta} = Y_1 + Y_2 \tag{25}$$

$$J\,\dot{r}_1 - m_2\,(b_1 + a_2)\,(\dot{v}_1 + Ur_1) - m_2 a_2 U\dot{\theta} - J_2\ddot{\theta} = aY_1 - (\ell_2 + b_1)Y_2 \tag{26}$$

If we make the further assumption that the hinge joint is rigid, then θ can be considered a fixed or known time variable parameter rather than a variable. Defining the front section sideslip angle,

$$\beta_1 \equiv v_1 \;/\; U \tag{27}$$

then allows Eqs. (25) and (26) to be written.

$$M\,U\,(\dot{\beta}_1 + r_1) - m_2\,(b_1 + a_2)\,\dot{r}_1 = Y_1 + Y_2 - m_2 a_2 \ddot{\theta} \tag{28}$$

$$J\,\dot{r}_1 - m_2(b_1 + a_2)U(\dot{\beta}_1 + r_1) = aY_1 - (\ell_2 + b_1)\,Y_2 + m_2 a_2 U\dot{\theta} + J_2\ddot{\theta} \tag{29}$$

Equations (28) and (29) are the equations of motion of the vehicle under the simplifying assumptions made in the preceding paragraphs. The dependent variables are the yaw rate of the front section, r_1, and the sideslip angle at the c.g. of the front section, β_1.

The tire side forces Y_1 and Y_2, can be derived neglecting camber and traction effects, roll steer, and compliances.

Assuming linear behavior,

$$Y_1 = C_1\alpha_1 \tag{30}$$

$$Y_2 = C_2\alpha_2 \tag{31}$$

where $C_{1,2}$ are the cornering stiffnesses

$\alpha_{1,2}$ are the slip angles

The slip angles can be defined in terms of velocities and geometry.

$$\tan \alpha_1 = \frac{v_1 + a_1 r_1}{u_1} \tag{32}$$

which for $u_1 = U$ and small α_1 becomes

$$\alpha_1 \simeq \beta_1 + \frac{a}{U} r_1 \tag{33}$$

$$\tan \alpha_2 = \frac{v_2 - b_2 r_2}{u_2}$$

$$= \frac{u_1 \sin \theta + (v_1 - b_1 r_1) \cos \theta - a_2 r_2 - b_2 r_2}{u_1 \cos \theta - (v_1 - b_1 r_1) \sin \theta} \tag{34}$$

For small angles θ and α_2 and $u_1 = U$, Eq. (34) becomes,

$$\alpha_2 \simeq \theta + \beta_1 - \left(\frac{b_1}{U}\right) r_1 - \frac{\ell_2}{U}(r_1 - \dot{\theta})$$

$$= \beta_1 - \left(\frac{\ell_2 + b_1}{U}\right) r_1 + \theta + \left(\frac{\ell_2}{U}\right) \dot{\theta} \tag{35}$$

Substituting Eqs. (34) and (35) into (30) and (31)

$$Y_1 = C_1 \left(\beta_1 + \frac{a_1 r_1}{U}\right) \tag{36}$$

$$Y_2 = C_2 \left[\beta_1 - \left(\frac{\ell_2 + b_1}{U}\right) r_1 + \theta + \frac{\ell_2}{U} \dot{\theta}\right] \tag{37}$$

and substituting Eqs. (36) and (37) into (28) and (29) gives, after some manipulation,

$$MU\dot{\beta}_1 - Y_\beta \beta_1 - m_2(b_1 + a_2)\dot{r}_1 + (MU - Y_r)r_1$$

$$= C_2(\theta + \frac{\ell_2}{U}\dot{\theta}) - m_2 a_2 \ddot{\theta} \tag{38}$$

where

$$Y_\beta \equiv C_1 + C_2 \tag{39}$$

$$Y_r \equiv \frac{a_1 c_1 - (b_1 + \ell_2)C_2}{U} \tag{40}$$

Similarly,

$$J\dot{r}_1 - [m_2 U(b_1 + a_2) + N_r]r_1$$

$$- m_2 U(b_1 + a_2)\dot{\beta}_1 - N_\beta \beta$$

$$= -(\ell_2 + b_1)C_2(\theta + \frac{\ell_2}{U}\dot{\theta}) - m_2 a_2 U\dot{\theta} + J_2\ddot{\theta} \tag{41}$$

where $N_\beta \equiv a_1 C_1 - (\ell_2 + b_1)C_2$ (42)

$$N_r \equiv \frac{a_1^2 C_1 + (\ell_2 + b_1)^2 C_2}{U} \tag{43}$$

Eqs. (38) through (43) represent a set of linear differential equations for β_1 and r_1, assuming small angle, θ, constant velocity, $u_1 = U$, and linear tire forces.

B-2 Stability Considerations

Taking the LaPlace transform of Eqs. (38) and (41) and writing them in matrix form,

$$\begin{bmatrix} (MUs - Y_\beta) & [-m_2(b_1 + a_2)s + (MU - Y_r)] \\ -[m_2U(b_1 + a_2)s + N_\beta] & [Js - (m_2U(b_1 + a_2) + N_r)] \end{bmatrix} \begin{bmatrix} \bar{\beta}_1(s) \\ \bar{r}_1(s) \end{bmatrix}$$

$$= \begin{bmatrix} -m_2a_2s^2 - C_2 \frac{\ell 2}{U} s + C_2 \\ -J_2s^2 - [\frac{\ell 2(\ell 2 + b_1)C_2}{U} + m_2a_2]s - (\ell_2 + b_1)C_2 \end{bmatrix} \bar{\theta}(s) \tag{44}$$

The stability of this system can be examined by determining the roots or eigenvalues of Eq. (44). These are determined by setting the left side of the equation equal to zero and solving for the roots of the polynomial in s.

$$A\,s^2 + B\,s + C = 0 \tag{45}$$

where

$$A = U[MJ - m_2^2\,(b_1 + a^2)^2] \tag{46}$$

$$B = -JY_\beta - U[MN_r + m_2(b_1 + a_2)Y_r] - m_2(b_1 + a_2)N_\beta \tag{47}$$

$$C = U[m_2(b_1 + a_2)Y_\beta + MN_\beta] + [Y_\beta N_r - Y_r N_\beta] \tag{48}$$

If we make a further assumption that the articulation angle is fixed (θ = constant), we can obtain a steady state solution for sideslip angle and yaw rate from Eq. (44) which becomes,

$$\begin{bmatrix} Y_\beta & MU - Y_r \\ -N_\beta & -[m_2U(b_1 + a_2)+N_r] \end{bmatrix} \begin{bmatrix} \beta_1 \\ r_1 \end{bmatrix} = \begin{bmatrix} C_2 \\ -(\ell_2 + b_1)C_2 \end{bmatrix} \theta \tag{49}$$

Solving for β_1 and r_1,

$$\beta_1 = \frac{-[N_r + m_2U(b_1 + a_2)]\ C_2 + (MU - Y_r)(\ell_2 + b_1)C_2}{\Delta} \tag{50}$$

$$r_1 = \frac{Y_\beta(\ell_2 + b_1)C_2 + N_\beta C_2}{\Delta} \tag{51}$$

where

$$\Delta = U[MN_\beta + m_2(b_1 + a_2)Y_\beta] + Y_\beta N_r - N_\beta Y_r \tag{52}$$

Δ can be defined as an understeer/oversteer parameter.

We will note, without actually deriving the equations, that the preceding analysis can be repeated for a front-wheel steered vehicle resulting in a simplified steady-state solution in which the understeer/oversteer parameter is of the form,

$$\Delta = MUN_\beta + Y_\beta N_r - Y_r N_\beta \tag{53}$$

It can be seen that the understeer/oversteer parameter for the articulated vehicle has an additional term. Also, the other force and moment parameters differ as follows:

Front-Wheel Steer	Articulated Steer
$Y_\beta = C_1 + C_2$	$Y_\beta = C_1 + C_2$
$N_\beta = aC_1 - bC_2$	$N_\beta = a_1c_1 - (\ell_2 + b_1)C_2$
$Y_r = \frac{aC_1 - bC_2}{U}$	$Y_r = \frac{a_1c_1 - (\ell_2 + b_1)C_2}{U}$
$N_r = \frac{a^2c_1 + b^2c_2}{U}$	$N_r = \frac{a_1^2c_1 + (\ell_2 + b_1)^2C_2}{U}$

B-3 Vehicle Geometry and Weight Distribution

It is possible to examine the under-oversteer parameter defined in the preceding section for a particular vehicle if we know details of the geometry and weight distribution for the vehicle. Although we do not have this data for any of the vehicles of interest, we know enough about the existing Army vehicles, the M4K and the M10A to make some good approximations. The geometry factors required are derived here.

Figure B-2 shows the centers of mass of the vehicle and the two body segments along with the various geometrical factors.

It is clear that,

$$a + b = \ell_1 + \ell_2 = \ell \tag{54}$$

The definition of the center-of-mass can be used to determine that,

$$w_1\,(b_1 + a - \ell_1) = w_2\,(a_2 - a + \ell_1) \tag{55}$$

which yields,

$$a = \frac{(\ell_1 + a_2)w_2 + (\ell_1 - b_1)w_1}{w} \tag{56}$$

since $$w_1 + w_2 = w \tag{57}$$

Eq. (54) then gives,

$$b = \frac{(\ell_2 - a_2)w_2 + (\ell_2 + b_1)w_1}{w} \tag{58}$$

Defining, $$\eta \equiv \frac{w_1}{w} \tag{59}$$

and substituting into Eqs. (56) and (58) gives,

$$a = \ell_1 + [a_2(1-\eta) - b_1\eta] \tag{60}$$

$$b = \ell_2 - [a_2(1-\eta) - b_1\eta] \tag{61}$$

Thus,

$$b_1 = \frac{(1-\eta)}{\eta}\,a_2 + \frac{(a - \ell_1)}{\eta} \tag{62}$$

$$a_1 = \ell_1 - b_1 \tag{63}$$

$$b_2 = \ell_2 - a_2 \tag{64}$$

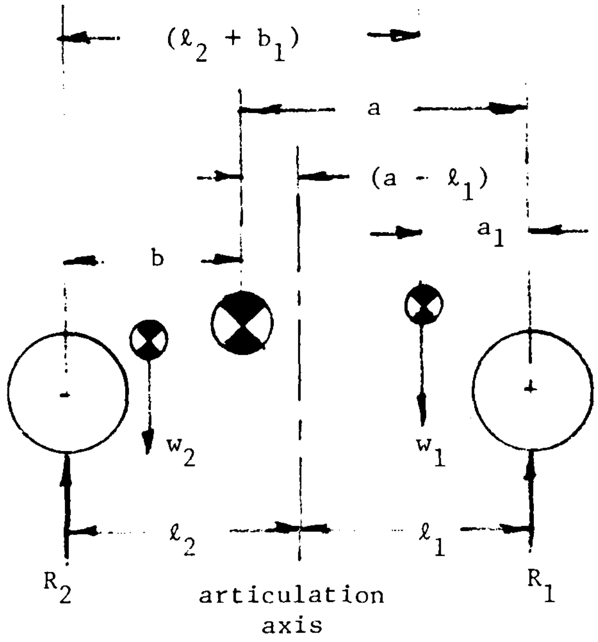

$(\ell_2 + b_1)$
a
$(a - \ell_1)$
a_1
b
w_2
w_1
ℓ_2
ℓ_1
R_2
articulation axis
R_1

Figure B-2

Mass Distribution and Geometry Factors for the Articulated Vehicle

B-4 Tire Data

The analysis in the preceding sections requires tire data on cornering stiffness for numerical solutions. Tire manufacturers were contacted and stated that this data is not available for the off-road vehicle tires used on the RTFLT's. However, data was found for similar sized truck tires in Reference (23). This is summarized in the graph of Figure B-3.

For the M10A, which uses 20.5 x 25 tires at 90 psi, the data was taken directly from Figure B-3. The front tire load is 6200 lbs. for a coefficient of 0.134. The rear tire load is 12,150 lbs. for a coefficient of 0.083. The corresponding cornering stiffnesses for two front and two rear tires are:

Front, $$C_1 = \frac{-(0.134)(12400)(180)}{\pi} = -95{,}210 \text{ lb/rad.}$$

Rear, $$C_2 = \frac{-(0.083)(24300)(180)}{\pi} = -115{,}570 \text{ lb/rad.}$$

For the M4K, the nominal inflation pressure is 45 psi instead of 90 psi and there is no available data at 45 psi. For front and rear individual tire loads of 2343 and 2520 lbs., respectively, Figure B-3 would give a cornering coefficient of about 0.15. It is known that this coefficient decreases as the pressure decreases. In lieu of any data, we have assumed for the purposes of a first approximation that the coefficient at 45 psi is 0.12. This allows the calculation of the cornering stiffnesses:

$$C_1 = \frac{-(0.12)(4685)(180)}{\pi} = -32{,}212 \text{ lb/rad.}$$

$$C_2 = \frac{-(0.12)(5040)(180)}{\pi} = -34{,}652 \text{ lb/rad.}$$

15-22.5/H TRUCK TIRE
@ 90 PSI

From "Mechanics of Pneumatic Tires", Ref. (23)

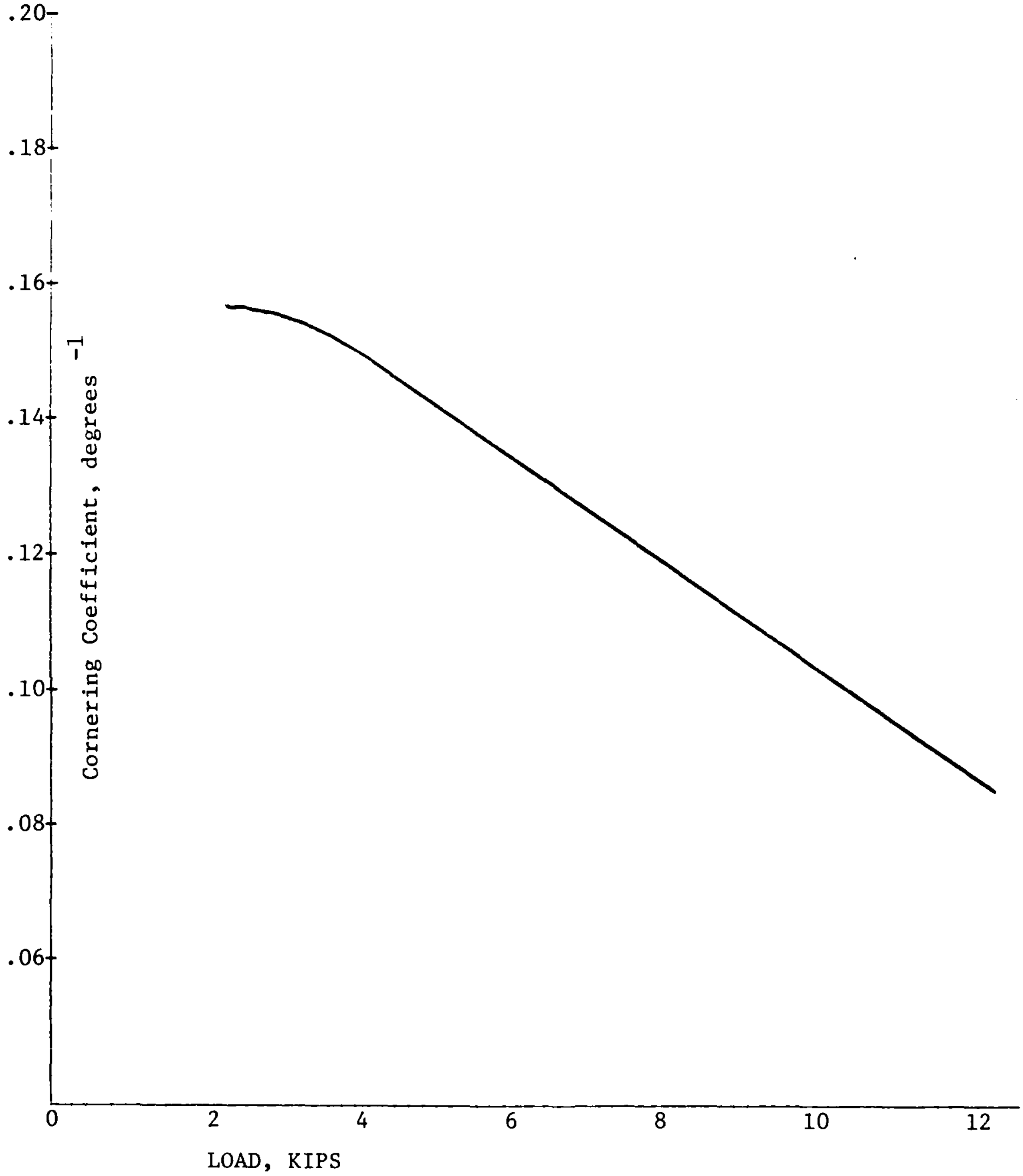


Figure B-3

Cornering Coefficient vs. Load

B-5 Vehicle Calculations

(a) M4K

An assumed weight distribution for the two body segments was made for the M4K using the following geometrical paramaters as covered in Section B-3.

$a_1 = a_2 = 23$ in. $= 1.9167$ ft.

$b_1 = b_2 = 23$ in. $= 1.9167$ ft.

$\ell_1 = \ell_2 = 46$ in. $= 3.8333$ ft.

$w_1 = 4507.5$ lbs.

$w_2 = 5217.5$ lbs.

$w = w_1 + w_2 = 9725$ lbs.

A second case was also calculated assuming that the centers of mass for the two segments were about one-half the above distances from the wheel centerlines. The results which will not be reproduced here showed the same critical speed.

The resulting force and moment parameters for the M4K are:

$$Y_\beta = C_1 + C_2 = -32{,}212 - 34{,}652 = -6.6864 \times 10^4 \text{ lb/rad.}$$

$$N_\beta = a_1 c_1 - (\ell_2 + b_1)C_2$$

$$= 1.9167\ (-32212) - (5.750)(-34652) = 13.75083 \times 10^4 \ \frac{\text{lb-ft}}{\text{rad.}}$$

$$UY_r = aC_1 - (\ell_2 + b_1)C_2 = 7.12622 \times 10^4 \ \frac{\text{lb-ft}}{\text{rad.}}$$

$$U\,N_r = a_1^2 c_1 + (\ell_2 + b_1)^2 C_2 = -126.40203 \times 10^4 \ \frac{\text{lb-ft}}{\text{rad.}}$$

The vehicle masses are:

$$M = \frac{w}{g} = \frac{9725}{32.5} = 302.02 \ \frac{\text{lb-sec}^2}{\text{ft.}}$$

$$m_2 = \frac{w_2}{g} = \frac{5217.5}{32.5} = 162.03 \ \frac{\text{lb-sec}^2}{\text{ft.}}$$

Substituting the above parameters into Eq. (52) gives,

$$\Delta = 59.52 \quad U \quad + \quad \frac{747.18309 \times 10^8}{U}$$

which can be written as,

$$U\Delta = 59.52\ (U^2 + 12.55 \times 10^8)$$

This shows that Δ is always positive and may be considered an understeer vehicle by this analysis. There is no critical speed at which an abrupt change in stability would occur.

A similar calculation can be performed assuming that the M4K has the same mass distribution but is steered by its front wheels instead of by body articulation. Here Eq. (53) and its corresponding relations for Y_β, N_β, Y_r and N_r are used. This calculation which will not be reproduced here shows that the vehicle would be expected to be oversteer but the critical speed is very high, of the order of 360 mph.

(b) M10A

Using the manufacturer data for the location of the center of mass and the wheel loading, the following weight distribution was assumed for the M10A:

$a_1 = 0$

$a_2 = 50$ in. $= 4.1666$ ft.

$b_1 = 48$ in. $= 4$ ft.

$b_2 = 10$ in. $= 0.8333$ ft.

$\ell_1 = 48$ in. $= 4$ ft.

$\ell_2 = 60$ in. $= 5$ ft.

$a = 71.51$ in. $= 5.959$ ft.

$b = 36.49$ in. $= 3.041$ ft.

$w_1 = 9920$ lbs.

$w_2 = 26{,}780$ lbs.

$w = w_1 + w_2 = 36{,}700$ lbs.

The resulting force and moment parameters for the M10A are:

$Y_\beta = C_1 + C_2 = -2.1078 \times 10^5$ lb/rad.

$N_\beta = 10.401 \times 10^5$ lb-ft/rad.

$UY_r = 10.401 \times 10^5$ lb-ft/rad.

$UN_r = -93.612 \times 10^5$ lb-ft/rad.

$$M = \frac{w}{g} = 1139.75\ \frac{\text{lb-sec}^2}{\text{ft.}}$$

$$m_2 = \frac{w_2}{g} = 831.68\ \frac{\text{lb-sec}^2}{\text{ft.}}$$

Substituting into Eq. (52) gives,

$$\Delta = -2.462 \times 10^{8} U + \frac{8.9134 \times 10^{11}}{U}$$

or $$U\Delta = -2.462 \times 10^{8} (U^{2} - 3620)$$

Thus, the critical speed is determined by,

$$U = (3620)^{1/2} = 60.2 \text{ ft/sec.}$$
$$= 41 \text{ mph}$$

Using the same weight distribution but assuming a non-articulated front wheel steering vehicle, Eq. (53) and its associated parameters can be used to obtain

$$U\Delta = 2.4609 \times 10^{8} [U^{2} - 3792]$$

which gives a critical speed,

$$U = (3792)^{1/2} = 61.6 \text{ ft/sec.}$$
$$= 42 \text{ mph}$$

which is virtually the same as that for the articulated vehicle.

Appendix C

Sources of Information Consulted During the Study

C.1 Overall Vehicle Design

1. J.I. Case
P.O. Box 5215
Terre Haute, IN 47805
Louis T. Jensen, Engineer, (812) 466-1236
Jerry A. Waite, Government Marketing, (414) 636-7546

2. Dresser Industries, Inc.
International-Hough Division
755 South Milwaukee Ave.
Libertyville, IL 60048
John Kurowski, Engineer, (312) 367-2354
Ken Houtz, Engineer, (312) 367-2370
Fred Wolter, Government Sales, (312) 367-2838

3. The Gradall Co.
406 Mill Ave., SW
New Philadelphia, OH 44663
Rich Liggett, Chief Engineer
Rod Reese, Manager, Military Sales (216) 334-2211

4. Coyote Loader Sales, Inc.
N.A. Distributors for Zettelmeyer
4300 Crane Centre Dr.
Streetsboro, OH 44240
Steve Kabay, President, (216) 562-4811

5. Standard Manufacturing Co., Inc.
Dallas, TX
Jim Kurowski, Engineer, (214) 337-8911

6. Harnischfeger Corp.
Milwaukee, WI 53201
William Stucker, Specialized Products

7. Deere & Co.
Moline, IL 61265
Victor C. Pierrot, Division Manager, Special Projects
William Long, Division Manager, Government Sales (309) 752-5581

8. Trantor International Ltd.
38 Station Rd.
Heaton Mersey, Stockport SK43QT
United Kingdom
G.A.B. Edwards, Chairman & Managing Director

9. The University of Leeds
Department of Mechanical Engineering
Leeds LSZ 9JT
United Kingdom
D.A. Crolla

C-2 Driveline Components

1. Clark Equipment Co.
Buchanan, MI
Roger Warner, Manager Government Sales and Applications
(616) 697-4467

2. Rockwell International Corp.
2135 West Maple Rd.
Troy, MI 48084
Larry Bowman, Manager, Off-Road Engineering
(313) 435-1501

3. Twin Disc, Inc.
Racine, WI 53403
Robert W. Bachmann, Application Engineer
(414) 634-1981

4. Dana Corp.
Spicer Division
P.O. Box 2424
Fort Wayne, IN 46801
Vince Kelble, (219) 483-7174

5. ZF of North America, Inc.
500 Barclay Blvd.
Lincolnshire, IL 60069
David L. Steinmuller, Account Manager
(312) 634-3500

6. SOMA of America, Inc.
P.O. Box 9368, Briarfield Sta.
Hampton, VA 23670
W. Douglas Richardson, Jr., Sales Representative
(804) 827-0310

7. Eaton Corp.
Axle and Brake Division
P.O. Box 4008
Kalamazoo, MI 49003
Rich Melkerson, (616) 342-3018

8. Borg and Beck
Division of Borg-Warner Corporation
6700 18 1/2 Mile Rd.
Sterling Heights, MI 48078
(313) 739-6000

C.3 Tires

1. The Goodyear Tire & Rubber Co.
   Technical Center
   Akron, OH 44316-0001
   A.V. Musci, (216) 796-3863
   Area Accounts Manager, Off-the-Road Tire Applications

2. Michelin Tire Corp.
   P.O. Box 19001
   Greenville, SC 29602
   Frank R. Grimaldi, (803) 234-5275
   Government Applications, Product Engineering Group

3. Firestone Tire & Rubber Co.
   Central Research Lab.
   Akron, OH
   Pieter Schuring, (216) 379-6973

Appendix D

Selected Component Specifications

Rockwell Axles

ROCKWELL FRONT NON-DRIVE AXLES

Axle Series	Rating ① Pounds (Kg)	Brake Types and Sizes ③ Inches (mm)		Hubs and Drums Studs, Bolt Cir, Dia. Inches (mm)
FC-901	7,000 (3175)	Cam-Master T Stopmaster	15 x 3.5 (381 x 89)	10 Stud, 11.25 (286)
FD-931	9,000 (4100)	Cam-Master T Stopmaster	15 x 4 (381 x 102)	
FF-971 Center-Point™	12,000 (5400)			
FF-941 Easy Steer	12,000 (5400)	Cam-Master T Stopmaster Stopmaster Cam-Master Q™ Dura-Master Air Disc	15 x 4 (381 x 102) 15 x 5 (381 x 127) 16.5 x 5 (419 x 127) ADB 1540	
FF-942 Easy Steer	13,200 (6000)	Cam-Master Q Stopmaster	16.5 x 5 (419 x 127) 15 x 5 (381 x 127)	
FG-941 Easy Steer	14,600 (6600)	Dura-Master Air Disc	ADB 1540	
FL-941 Easy Steer	20,000 (9100)	Cam-Master Q Stopmaster Stopmaster Dura-Master Air Disc™	15 x 6 (381 x 152) 17 x 6 (432 x 152) ADB 1560	10 Stud, 11.25 (286) 10 Stud, 13.19 (335)
FL-951	22,000 (10000)	Stopmaster	17 x 6 (432 x 152)	
FU-910	28,000 (12700)	Cam-Master	20.25 x 5 (514 x 127)	10 Stud, 13.19 (335)

ROCKWELL FRONT DRIVE AXLES

Axle Series	Capacity Pounds (Kg)	Ratios (Others Available)	Brake Types and Sizes Inches (mm)	Hubs and Drums Studs, Bolt Cir. Dia. Inches (mm)
FDS-75	7,500 (3400)	6.14, 6.20, 6.80, 6.83, 7.20	Hydraulic Disc 15.4 x 1.5 (391 x 38)	6 Stud, 8.75 (222.3) Cast spoke wheels
FDS-90	9,000 (4100)	6.14, 6.20, 7.20	Stopmaster Air/Hyd. 15 x 4 (381 x 102) Hydraulic Disc 15.4 x 1.5 (391 x 38)	10 Stud, 11.25 (286) Cast spoke wheels
FDS-1600	16,000 (7300)	4.63, 5.29, 5.83, 6.17, 6.50, 7.20, 7.80, 8.20	Stopmaster Air/Hyd 17.25 x 4 (438 x 102)	10 Stud, 11.25 (286)
FDS-1805	21,000 (9500)	Double Reduction — 5.91, 6.38, 7.42, 8.04, 8.69, 9.04, 9.76, 10.11, 11.36⑫	Stopmaster Air/Hyd. 17 x 6 (432 x 152)	10 Stud, 11.25 (286) 10 Stud, 13.19 (335)
FDS-1807		Single Reduction — LH Gearing 4.11, 4.33, 4.62, 4.89, 5.29, 6.17, 7.40		
FDS-1808		Single Reduction — RH Gearing 4.11, 4.63, 5.29, 6.17, 7.40		
FDS-2100	21,000 (9500) 23,000 (10500)④	Single Reduction — RH Gearing 4.11, 4.63, 5.29, 6.17, 7.40		
FDS-2101		Single Reduction — LH Gearing 4.11, 4.33, 4.62, 4.89, 5.29, 6.17, 7.40		
FDS-2102		Double Reduction — 5.91, 6.38, 7.42, 8.04, 8.69, 9.04, 9.76, 10.11, 11.36⑫		

Axle Series	Rating① Pounds (Kg)	GCW① Pounds (Kg)		Description	Ratios (Others Available)	Housing Size at Spring Seat Inches (mm)	Housing Wall Thickness at Spring Seat Inches (mm)	Brake Types and Sizes③ Inches (mm)	Hubs and Drums Studs, Bolt Circle Dia. Inches (mm)
		Highway							
		Turnpike	Paved②						
D-140	13,000 (5900)	29,000 (13000)	29,000 (13000)	Hypoid Sing. Red.	4.88, 5.29, 5.83, 6.20. 6.80, 7.80	4.25 x 3.8125 (108 x 96.8)	.375 (9.5)		6 Stud, 8.75 (222)
F-106	15,000 (6800)	35,000 (16000)	35,000 (16000)	Hypoid Sing. Red.	5.29, 5.83, 6.14, 6.83, 7.17	4.25 x 3.8125 (108 x 96.8)	.375 (9.5)	Stopmaster 15 x 5 (381 x 127)	6 Stud, 8.75 (222)
H-172	17,500 (8000)	50,000 (23000)	50,000 (23000)	Hypoid Sing. Red.	3.73, 4.10, 4.56, 4.88, 5.38, 5.86, 6.14, 6.83, 7.17, 7.80, 8.20	5 x 4.25 (127 x 108)	.375 (9.5)	Cam-Master 16.5 x 5 (419 x 127) Cam-Master 16.5 x 6 (419 x 152) Stopmaster 15 x 6 (381 x 152) Dura-Master Air Disc ADB-1560	10 Stud, 11.25 (286)
L-172	18,500 (8400)	50,000 (23000)	50,000 (23000)	Hypoid Sing. Red.	3.73, 4.10, 4.56, 4.88, 5.38, 5.86, 6.14, 6.83, 7.17, 7.80, 8.20	5 x 4.25 (127 x 108)	.375 (9.5)	Cam-Master 16.5 x 7 (419 x 178) Stopmaster 15 x 7 (381 x 178) Dura-Master Air Disc ADB 1560	
M-172	20,000 (9100)	50,000 (23000)	50,000 (23000)	Hypoid Sing. Red.	3.73, 4.10, 4.56, 4.88, 5.38, 5.86, 6.14, 6.83, 7.17, 7.80, 8.20	5 x 4.25 (127 x 108)	.375 (9.5)		
Q-100	22,000 (10000)	65,000 (30000)	65,000 (30000)	Hypoid Sing. Red.	3.55, 3.73, 3.90, 4.10, 4.33, 4.44, 4.63, 4.88, 5.29, 5.86, 6.14, 6.83, 7.17, 7.80	5.25 x 4.625 (133 x 117)	.375 (9.5)		
R-155	23,000 (10500)	75,000 (34000)	65,000 (30000)	Hypoid Sing. Red.	3.36, 3.73, 3.91, 4.10, 4.30, 4.56, 4.89, 5.38, 5.57, 6.14, 7.33 ⑫	5.25 x 4.625 (133 x 117)	.50 (13)		
R-255	23,000 (10500)	85,000 (39000)	85,000 (39000)	Hyp. Hel. Dble. Red.	4.64, 5.91, 9.76, 11.36, 12.82	5.25 x 4.625 (133 x 117)	.50 (13)		
RL-170 ⑤	20,000 (9100)	127,000 (58000)	100,000 (45000)	Hypoid Sing. Red.	3.42, 3.55, 3.70, 3.90, 4.11, 4.33, 4.63, 4.88, 5.29, 5.57, 5.86, 6.14, 6.83, 7.40	5.25 x 4.625 (133 x 117)	.375 (9.5)		
R-170 ⑤ ⑩	23,000 (10500)	127,000 (58000)	100,000 (45000)	Hypoid Sing. Red.	3.42, 3.55, 3.70, 3.90, 4.11, 4.33, 4.63, 4.88, 5.29, 5.57, 5.86, 6.14, 6.83, 7.40	5.25 x 4.625 (133 x 117)	.50 (13)		
R-270	23,000 (10500)	127,000 (58000)	100,000 (45000)	Hyp. Hel. Dble. Red.	5.49, 6.10, 6.43, 6.86, 7.23, 7.84, 9.11, 10.13, 10.97	5.25 x 4.625 (133 x 117)	.50 (13)		
S-170	26,000 (12000)	127,000 (58000)	100,000 (45000)	Hypoid Sing. Red.	3.70, 3.90, 4.11, 4.33, 4.63, 4.88, 5.29, 5.57, 6.14, 6.83, 7.40	5.50 x 5.50 (140 x 140)	56 (14)	Cam-Master 16.5 x 7 (419 x 178)	
U-170	30,000 36,000 ④ (13600, 16400)	127,000 (58000)	100,000 (45000)	Hypoid Sing. Red	3.70, 3.90, 4.11, 4.33, 4.63, 4.88, 5.29, 5.57, 6.14, 6.83, 7.40	5.50 x 5.50 (140 x 140)	.56 (14)	Cam-Master 16.5 x 7 (419 x 178) Cam-Master 18 x 7 (457 x 178)	10 Stud, 11.25 (286) 10 Stud, 13.19 (335)
U-240	29,000, 36,000 ④ (13200, 16400)	85,000 (39000)	85,000 (39000)	Hyp. Hel. Dble. Red.	5.91, 6.38, 6.51, 7.03, 7.21, 7.79, 8.65, 9.76, 10.46, 11.36, 14.53	5.50 x 5.50 (140 x 140)	56 (14)		
U-270	30,000, 36,000 ④ (13600, 16400)	127,000 (58000)	100,000 (45000)	Hyp. Hel. Dble. Red.	5.49, 6.10, 6.43, 6.86, 7.23, 7.84, 9.11, 10.13, 10.97	5.50 x 5.50 (140 x 140)	.56 (14)		
W-170	38,000 42,000 ④ (17300, 19000)	127,000 (58000)	100,000 (45000)	Hypoid Sing. Red	3.70, 3.90, 4.11, 4.33, 4.63, 4.88, 5.29, 5.57, 6.14, 6.83, 7.40	6.50 x 5.50 (165 x 140)	.66 (17)		
W-270	38,000 42,000 ④ (17300, 19000)	127,000 (58000)	100,000 (45000)	Hyp. Hel. Dble. Red	5.49, 6.10, 6.43, 6.86, 7.23, 7.84, 9.11, 10.13, 10.97	6.50 x 5.50 (165 x 140)	66 (17)		

Rockwell planetary axles are designed for a wide range of heavy-duty applications. Steering axles, rigid axles, tandems and tridems . . . all with a wide selection of gear reductions, capacities, brakes and vehicle mounts to meet special needs.

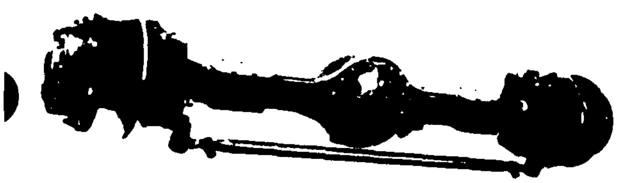
Whether on- or off-highway — huge dumps or heavy-haulers — rough terrain or truck mounted cranes — front end loaders, lift trucks, log skidders or other special purpose vehicles; there is probably a Rockwell axle combination to meet your needs.

All Rockwell planetary axles feature rugged rectangular shaped axle housings, strong dependable axle shafts and gearing designed and engineered to meet your requirements.

Planetary tandem and tridem axles feature through-drive in-line design with optional driver controlled inter-axle differential to provide maximum utilization of pulling power in off-road use as well as speed and versatility for highway travel. Optional overdrive carriers provide ratios that are designed to maintain the minimum speeds required by most states for highway travel.

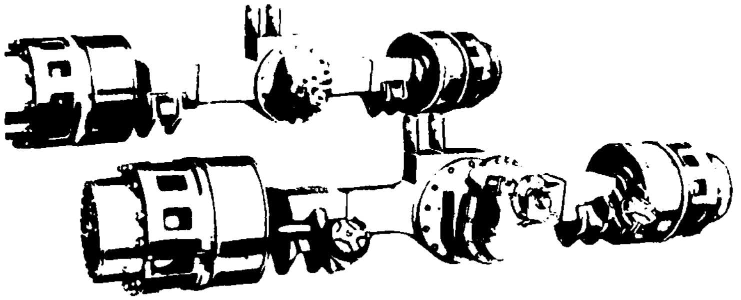
Special TA-Series transmission/axle combination assemblies are available for smaller lift trucks and other short wheel base vehicles.

AXLE SERIES	TYPICAL USAGE ①			OVERALL RATIOS	TRACK RANGE
	VEHICLE	LBS.	KGS.		
NSM-820 (2)	R.T CRANE	27.000	12.247		80"-81 38" 2032 MM - 2067 MM
PSS-165 PSS-166	SPECIAL PURPOSE	12,500	5.760	14 30, 15 26, 16 09, 17 44, 19 25, 20 46, 22 44 23 76, 25 74	67" - 79 5" 1702 MM - 2019 MM
PSC-204 PSC-205	REACH TRUCK	20,000	9.070	14 30, 16 09, 17 44, 19 25, 20 27, 20 46, 22 44, 22 55, 23 76, 25 74	79 5"-83" 2019 MM -2108 MM.
PSC-353	R T CRANE REACH TRUCK	22,000	10.000	14 30, 16 09, 17 44, 19 25, 20 27, 20 46, 22 44, 22 55, 23 76, 25 74	80" 2032 MM
PSC-593 PSC-594	R T CRANE	25,000	11.337	15 60, 17 55, 19 03, 21 00, 22 11, 22 32, 24 48, 24 60, 25 92, 28 08 16 65, 16 09, 17 44, 17 55, 20 06, 21 00, 22 11, 22 32, 24 48, 24 60, 25 08, 25 92, 28 08	79"-84" 2007 MM -2134 MM
PSM-593 PSM-594	R.T CRANE	25,000	11.340	15 60, 16 65, 17 55, 19 03, 21 00, 22 32, 24 48, 25 92, 28 08	75" - 80 7" 1905 MM - 2050 MM
PSM-596	R.T CRANE	25,000	11.340	13 32, 13 42, 14 76, 14 80, 16 65, 19 03, 21 00, 22 20, 24 48, 24 60, 25 80, 25 92, 28 08, 29 52	81" - 82" 2057 MM - 2083 MM
PSC-723	R.T CRANE	28,500	12.930	17 94, 20 65, 22 39, 24 70, 26 02, 26 26 28 80, 28 94, 30 49, 33 03	81" (2057 MM.)
PSM-824 PSC-824 PSOC-824 (Trunnion-Mount)	R T CRANE	28,000 30,000	12.701 13.608	13 32, 13 42, 14 76, 14 80, 16 65 19 03, 21 00, 22 20, 24 48, 24 60, 25 80, 25 92, 28 08, 29 52	80"-99" 2032 MM.- 2515 MM.
PSM-826	R.T CRANE	35,000	15,876	13 32, 14 80, 16 65, 17 55, 19 03, 21 09, 22 20, 24 60, 25 80, 25 92, 26 64, 28 08	81 38" - 114" 2067 MM - 2642 MM.
PSM-1044 PSC-1045	R.T CRANE	35,000	15,876	12 11, 13 32, 14 80, 16 65, 17 55, 19 03, 21 09, 22 20, 24 60, 25 80, 25 92, 26 64, 28 08	81 375" - 96" 2067 MM - 2438 MM
PSM-1614 PSC-1614	R.T CRANE	49,000 53,000	22,226 24,041	13 32 14 80 16 65 17 55 19 03 21 09 22 20 24 60 25 80 25 92 26 64 28 08 15 67 17 41 20 65 21 56 22 39 24 80 26 12 28 94 30 35 30 49 31 34 33 03	87.5" - 101" 2223 MM - 2565 MM
PSC-1615	R T CRANE	50,000	22.675	12 11, 13 42, 14 40, 14 80, 16 65, 19 03, 21 00, 22 20, 23 40, 26 64 14 25, 15 78, 16 52, 17 41, 19 59, 22 39, 24 70, 26 12, 28 94, 31 34	87 5"-101" 2223 MM -2565 MM
PSLM-1616	SPECIAL PURPOSE	40,000	18.144	12 31 12 76 13 32 14 04 14 80 15 60 16 00 16 65 17 55 19 03 21 00 22 20 24 60 25 92 28 08 30 96 Drop Box 9 14 9 48 9 90 10 43 11 00 11 59 11 89 12 37 13 04 14 14 15 60 16 50 18 28 19 26 20 86 23 00	100" - 119" 2540 MM - 3023 MM
PSC-1875	R.T CRANE	60,000	27.216	17 49 19 38 20 28 21 38 22 53 24 05 25 42 27 49 28 97 30 33 32 07 35 53 38 48	99" - 121" 2515 MM - 3073 MM
PSC-4564	R T CRANE	70,000	31.752	17 49 19 38 20 28 21 38 22 53 24 05 25 42 27 49 28 97 30 33 32 07 35 53 38 48	112" 2845 MM

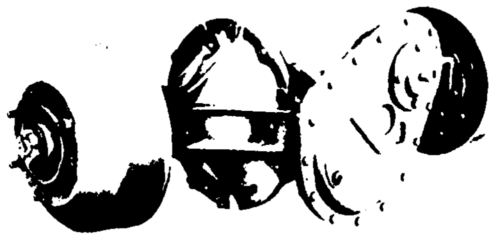


PS-SERIES, planetary steering axles

PR-SERIES, planetary rigid axles



SPR-SERIES, tandem planetary axles



TA-SERIES, combination transmission/axle assemblies

BRAKES	MIN. RIM SIZE	HUB & DRUM	CARRIER	PLANET GEAR RATIO	FOOTNOTES
17 25" x 4" H (438 MM x 102 MM)	24" 610 MM	12 Stud - 16 63 BC - 422 MM			
16" x 2 25" H (406 MM x 57 MM)	24" 610 MM	8 Stud 15 00" BC 381 MM	D-140 F-140	3 3 1	1 The loads shown represent typical usage of these axles Actual permitted use varies with type of vehicle and type of service Individual installations must be approved by Rockwell Off-Highway Engineering 2 Non-drive steering axle
16.5" x 5.5" H (419 MM. x 127 MM) 18" x .526" Dry Disc (457 MM x 159 MM)	20" 508 MM 24" 610 MM	8 Stud 15 00 BC 381 MM	D-140 F-140	3 3 1	
17" x 4" DLH 18" x 625 Dry Disc	24" 610 MM	12 Stud 16 35" BC 422 MM	D-140	3 3 1	
17 x 4" DLH (432 MM x 102 MM) 18" x 625 Dry Disc (457 MM x 159 MM)	24 610 MM	12 Stud 16 63" BC - 422 MM	D-140 F-140	3 6 1	
17" x 4" H (432 MM x 102 MM) 17 25" x 4" H (438 MM x 102 MM)	24" 610 MM	12 Stud 16 63" BC 422 MM	D-140 F-140	3 6 1	
17" x 4 " H (432 MM x 102 MM) 17 25" x 4" H (438 MM x 102 MM)	24" 610 MM	12 Stud - 16 63" BC - 422 MM	H-140 H-172	3 6 1	
17" x 4" DLH (432 MM x 102 MM)	24" 610 MM	12 Stud 18 11 BC - 460 MM	D-142	4 235 1	
17.25" x 4" H (438 MM. x 102 MM) 20.25" x 4" RSA (514 MM. x 102 MM) 19.5" x 1" Dry Disc (495 MM. x 25 MM)	24" 610 MM	12 Stud - 16 63" BC - 422 MM	H-140 H-172	3 6:1 4 2 35:1	
17 25" x 4" H (438 MM x 102 MM) 20 25" x 4" RSA (514 MM x 102 MM) 20 25" x 5" P (514 MM x 127 MM)	24" 610 MM	12 Stud - 16 63" BC - 422 MM	Q-100	3 6:1	
20 25 x 4 RSA (514 MM x 102 MM) 20 25 x 4 RSH (514 MM x 102 MM) 20 25 x 4 P (514 MM x 102 MM)	24" 610 MM	12 Stud - 16 63" BC - 422 MM	Q-100 R-140	3 6 1	
20 25" x 4" RSA (514 MM x 102 MM) 20 25" x 4" RSH (514 MM x 102 MM)	25" 635 MM	23 Stud 16 63" BC 422 MM	Q-100	3.6:1 4 235:1 Opt.	
20 25" x 4" RSA, RSH 20 25" x 4" RSA, RSH (514 MM x 102 MM) 19 5" x 1" Dry Disc (495 MM x 25 MM)	25" 635 MM	23 Stud 16 63 BC 422 MM 22 Stud 16 63" BC 422 MM	R-155	3 6 1 4 235 1 Opt	
20 25" x 4" RSA (514 MM x 102 MM)	25 635 MM	12 Stud - 17 38 BC 441 MM	SQHP	3 6 1	
20" x 4" RDA (508 MM x 102 MM)	25 635 MM	22 Stud 19 5 BC 495 MM	R-140	5 2 1	
20 25 x 4 P (514 MM x 102 MM) 28 x 8 RSA (711 MM x 203 MM)	25 635 MM 29 737 MM	23 Stud 19 5 BC 495 MM 31 Stud 19 5 BC 495 MM	R-140 R 155	5 2 1	

AXLE SERIES	TYPICAL USAGE ①			OVERALL RATIOS	TRACK RANGE
	VEHICLE	LBS.	KGS.		
PRTA-134	COMPACTOR	7,500	3,402	13 57, 15.56, 16 97, 18 70, 19.25, 20 35, 22.00, 22 44	41 25" - 54 4" 1048 MM - 1384 MM
PRA-164	COMPACTOR	9,500	4,309	13 57, 15 56, 16.97, 18.70, 19.25, 20.35, 22 00, 22.44	54 5" - 61 38" 1384 MM - 1559 MM
PRS-204 PRS-205	SPECIAL PURPOSE LOADER LIFT TRUCK	10,000 14,000 21 000	4,536 6,350 9,526	14.30, 15 26, 16 09, 17.44, 19 25, 20 46, 22 44, 23.76, 25 74	63 75" - 80 75" 1619 MM - 2051 MM
PRC-204 PRC-205	LOADER	11,000	4,990	14.30, 16.09, 17 44, 19.25, 20.27, 20.46 22 44, 22.55, 23.76, 25.74	37.6"-41.6" 955 MM.-1057 MM.
PRS-264 PRS-265	SPECIAL PURPOSE LOADER LIFT TRUCK	11,000 16,000 21,000	4,990 7,258 9.526	15 60, 16 65, 17 55, 19 03, 21 00, 22 32, 24 48, 25 92, 28 08	61 2" - 68 0" 1554 MM. - 1727 MM
PRC-265	REACH TRUCK	27,000	12,272	16 65, 16.09, 17.44, 17 55, 20 06, 21 00, 22 11, 22.32, 24 48, 24.60, 25 80, 25.92, 28.08	82" 2083 MM.
PRC-593 PRC-594	SPECIAL PURPOSE LOADER	14,000 18,000	6,350 8,165	15 60, 16 65, 17 55, 19 03, 21 00, 22 32, 24.48, 25 92, 28 08	63" - 88 25" 1600 MM. - 2242 MM
PRS-596	SPECIAL PURPOSE LOADER LIFT TRUCK	14,000 18,000 21,000	6,350 8,165 9,526	13.32, 13 42, 14.76, 14 80, 16.65, 19 03 21.00, 22 20, 24.48, 24.60, 25.80, 25.92, 28.08, 29.52	72.5" - 94" 1842 MM. - 2388 MM
PRLC-614	LIFT TRUCK	45,000	20,412	13.32, 13.42, 14.76, 14.80, 16.65, 19.03, 21.00, 22.20, 24.48, 24.60, 25.80, 25.92, 28.08, 29 52	71 25" - 78 75" 1810 MM. - 2000 MM
PRC-672 PRC-673	SPECIAL PURPOSE LOADER	22,000 24,000	9,979 11,159	13.32, 13.42, 14 76, 14.80, 16.00, 16 65, 19 03, 21 00, 22 20, 23.40, 24 48, 24.60, 25.80, 25.92, 26.64, 28.08, 29.52	63" - 93" 1600 MM. - 2362 MM
PRC-676	LOADER	24,000	11,159	12 31, 12 76, 13.32, 14 04, 14.80, 15.60, 16 00, 16 65, 17.55, 19 03, 21.00, 22.20, 24.60, 25.92, 28.08, 30 96	79" - 81.25" 2007 MM - 2064 MM
PRLC-824	LIFT TRUCK	60,000	27,216	13.42, 14.76, 16.65, 17.60, 19.03, 21 00, 22 20, 24 60, 25.80, 28 08, 29.52	38.38" - 43" 975 MM. - 1092 MM
PRLM-855	LIFT TRUCK	65,000	29,484	13.42, 14.76, 16. 65, 17.60, 19.03, 21 00, 22.20, 24.60, 25.80, 28.08, 29.52	75.5" - 78.5" 1918 MM - 1994 MM
PRC-863 PRC-864	SPECIAL PURPOSE	13,000	5,897	13 32, 13.42, 14.76, 14.80, 16.65, 19 03, 21.00, 22 20, 24.48, 24.60, 25.80, 25.92, 28.08, 29.52	85" - 87" 2159 MM - 2210 MM
PRC-1103 PRC-1104 PRC-1105	LOG SKIDDER LOG SKIDDER LOG SKIDDER	6	—	19.59, 22.39, 24.70, 26.12, 28.80 19.59, 20.70, 22.39, 24.70, 26.12, 28.94 19 59, 20.70, 22.39, 24.70, 26.12, 28.94	81"-92" 2057 MM.-2377 MM.
PRC-1314 PRC-1315	SPECIAL PURPOSE LOADER	31,000 37,500	14,062 17,010	17 49, 19 24, 21.38, 22.53, 24.05, 25.35, 25.42, 27.49, 28 97, 30.46, 32.07, 35.53, 37.27, 37.44, 38.48, 40.56	56 7"-108" 1440 MM. - 2743 MM
PRM-1615	SPECIAL PURPOSE LOADER	32 000 37,500	14,515 17,010	17 49, 19 38, 20.28, 21 38, 22.53, 24.05, 25.42, 27.49, 28.97, 32.07, 35.53, 38.48	97 5" - 116.38" 2477 MM. - 2959 MM.
PRC-1615	LOADER	40,000	18,182	21.38, 22.53, 24.05, 25.35, 25.42, 27.49, 28.97, 30.46, 31.94, 32.07, 35.53, 38.48	75"-81.4" 1905 MM.-2068 MM.
PRLC-1736 PRLC-1737	SPECIAL PURPOSE	38,500	17,500	18.43, 19.24, 20.28, 21.38, 22.53, 23.19, 24 05, 25.35, 27 49, 30.33, 32.07, 35.53	82"-108" 2083 MM.-2743 MM.
PRC-1756 PRC-1757	LOADER	37,500	17,010	12 11, 13.32, 14 80, 16.65, 17 55, 19 03, 21 09, 22.20, 24 60, 25 80, 25 92, 26 64, 28 08	86.75" - 91" 2204 MM. - 2311 MM
PRLC-1756 PRLC-1757	LIFT TRUCK	70,000	31,752	12 11, 13 32, 14 80, 16 65, 17 55, 19 03, 21 09, 22 20, 24 60, 25 80, 25 92, 26 64, 28 08	74" - 78.5" 1880 MM. - 1994 MM
PRC-1925	LIFT TRUCK	85,000	38 556	11 54, 12 69, 14 10, 14.80, 14 86, 15 86, 16 28, 16 77, 18 09, 18.13, 19.07, 19 11, 20 35, 21 15, 21.51, 23.26, 23 44, 24.51, 25 38, 27 13, 30.07, 32 56	86" - 88" 2184 MM - 2235 MM

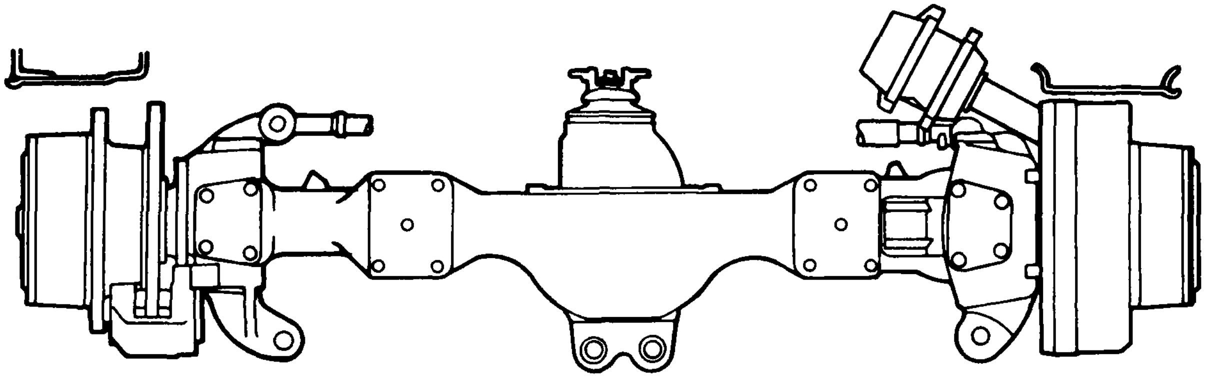
BRAKES	MIN. RIM SIZE	HUB & DRUM	CARRIER	PLANET GEAR RATIO	FOOTNOTES
12.5″ x 2.25″ FSH HYD (318 MM. x 57 MM.) 17″ x 3″ H (432 MM. x 76 MM.)	20″ 508 MM. 24″ 610 MM.	8 Stud - 15″ BC - 381 MM.	53500	3.3:1	1 The loads shown represent typical usage of these axles. Actual permitted use varies with type of vehicle and type of service. Individual installations must be approved by Rockwell Off-Highway Engineering. 6 Suitable for 25000 lb vehicles
12.5″ x 2.25″ FSH HYD (318 MM. x 57 MM.) 17″ x 3″ H (432 MM. x 76 MM.)	20″ 508 MM. 24″ 610 MM.	8 Stud - 15″ BC - 381 MM.	53500	3.3:1	
16″ x 3.5″ H (406 MM. x 89 MM.) 16.5″ x 5.5″ H (419 MM. x 140 MM.) 16″ x 2.25″ H (406 MM. x 57 MM.) 16.5″ x 5″ P (419 MM. x 127 MM.) 18″ x .625″ Dry Disc (457 MM. x 16 MM.)	20″ 508 MM. 24″ 610 MM	8 Stud - 15″ BC - 381 MM	D-140 F-140	3.3:1	
13″ Wet Disc (330 MM.)	20″ 508 MM.	8 Stud - 15″ BC - 381 MM.	D-140 F-140	3.3:1	
16.5″ x 2.5″ H (419 MM. x 64 MM.) 16.5″ x 5″ P (419 MM. x 127 MM.) 18″ x .625″ Dry Disc	24″ 610 MM	8 Stud - 15″ BC - 381 MM	D-140 F-140	3.6:1	
17″ x 4″ DLH (432 MM. x 102 MM.)	24″ 610 MM.	8 Stud - 15″ BC - 381 MM.	F-140	3.6:1	
16″ x 3.5″ H (406 MM. x 89 MM.) 17″ x 3″ H (432 MM. x 76 MM.) 17″ x 4″ H (432 MM. x 102 MM.) 18″ x .625 Dry Disc (457 MM. x 16 MM.) 13″ Wet Disc (330 MM.)	24″ 610 MM.	8 Stud - 15″ B.C. - 381 MM. 12 Stud - 16.63″ BC - 422 MM	D-140 F-140	3.6:1 4.24:1 Opt. 5.2:1 Opt.	
16.5″ x 2.25″ H (419 MM. x 64 MM.) 16.5″ x 5″ P (419 MM. x 127 MM.) 18″ x .625″ Dry Disc (457 MM. x 16 MM.)	24″ 610 MM.	12 Stud - 16.63″ BC - 422 MM.	H-140 H-172	3.6:1	
15″ x 3″ H (381 MM. x 76 MM.) 17.25″ x 4″ H (438 MM. x 102 MM.) 17.25″ x 4″ RSH (438 MM. x 102 MM.) 17.25″ x 4″ RSA (438 MM. x 102 MM.)	24″ 610 MM	10 Stud - 17.38″ BC - 442 MM. 12 Stud - 17.38″ BC - 442 MM.	H-140 H-172	3.6:1	
16.5″ x 5″ P (419 MM. x 127 MM.) 17.25″ x 4″ H (438 MM. x 102 MM.) 17.25″ x 4″ RDH (438 MM. x 102 MM.) 17.25″ x 4″ RSH (438 MM. x 102 MM.) 18″ x .625″ Dry Disc (457 MM. x .625″) 13″ Wet Disc (330 MM.)	24″ 610 MM.	12 Stud - 16.63″ BC - 422 MM.	H-140/172 L-172	3.6:1 4.24:1 Opt.	
17.25″ x 4″ H (438 MM. x 102 MM.) 17.25″ x 4″ RSH (438 MM. x 102 MM.)	25″ 635 MM	12 Stud - 16.63″ BC - 422 MM	Q-100	3.6:1 4.24:1 Opt.	
17.25″ x 4″ H (438 MM. x 102 MM.) 13″ Wet Disc (330 MM.)	25″ 635 MM.	15 Stud - 16.63″ BC - 422 MM.	H-172	3.6:1	
17.25″ x 4″ RSH (438 MM. x 102 MM.) 17.25″ x 4″ RSA (438 MM. x 102 MM.)	24″ 610 MM.	12 Stud - 17.38″ BC - 442 MM	L-172	3.6:1	
17.25″ x 4″ H (438 MM. x 102 MM.)	25″ 635 MM.	12 Stud - 16.63″ BC - 442 MM.	H-140/172 L-172	3.6:1	
None	20″ 508 MM.	12 Stud - 16.63″ BC - 422 MM.	H-140/172 L-172 QR-100	4.235:1	
18″ x .625 Dry Disc (457 MM. x 15.9 MM.) 20.25″ x 5″ P (514 MM. x 127 MM.) 17″ Wet Disc (432 MM.)	24″ 610 MM. 25″ 635 MM.	23 Stud - 19.75″ BC - 502 MM.	Q-100 R-140	5.2:1	
20.25″ x 5″ P (514 MM. x 127 MM.)	25″ 635 MM.	23 Stud - 19.5″ BC - 495 MM.	R-140	5.2:1	
17.25″ x 4″ (438 MM. x 102 MM.)	25″ 635 MM.	23 Stud - 19.75″ BC - 502 MM.	R-155	5.2:1	
None	25 635 MM.	23 Stud - 19.75″ BC - 502 MM.	QR-100	4.235:1	
20.25″ x 4″ RSH (514 MM. x 102 MM.) 20.25″ x 5″ P (514 MM. x 127 MM.)	25″ 635 MM.	12 Stud - 16.63″ BC - 442 MM.	Q-100 R-140	3.6:1 4.24:1 Opt.	
17.25″ x 4″ H (438 MM. x 102 MM.) 17.25″ x 4″ RSH (438 MM. x 102 MM.) 17.25″ x 4″ RSA (438 MM. x 102 MM.) 16.5″ x 7″ P (419 MM. x 178 MM.) 18″ x 7″ P (457 MM. x 178 MM.) 20.25″ x 7″ P (514 MM. x 178 MM.)	24″ 610 MM	8 Stud - 17.38″ BC - 442 MM. 10 Stud - 17.38″ BC - 442 MM. 12 Stud - 16.63″ BC - 422 MM. 12 Stud - 20.38″ BC - 518 MM. 19 Stud - 17.38″ BC - 442 MM. 23 Stud - 16.63″ BC - 422 MM.	Q-100 R-140	3.6:1	
20.25″ x 7″ P (514 MM. x 178 MM.) 17″ Wet Disc (432 MM.)	25″ 635 MM.	12 Stud - 21.38″ BC - 543 MM. 22 Stud - 21.38″ BC - 543 MM.	R-140	3.43:1 4.4:1 Opt.	

AXLE SERIES	TYPICAL USAGE ①			OVERALL RATIOS	TRACK RANGE
	VEHICLE	LBS.	KGS.		
PRC-3795 PRC-3796	LOADER	45,000	20,412	17.49, 17.77, 18.43, 19.24, 19.38, 20.28, 21.38, 22.53, 24.05, 25 35, 25.42, 27.49, 28.97, 30.46, 31.94, 32 07, 35.53, 38.48	76" - 113.38" 1930 MM - 2880 MM
PRC-4264	LOADER	50,000	22,680	17 76, 18.43, 19.24, 20.28, 21.38, 22.53, 24.05, 25.35, 27.49, 28.97, 30.46, 31.94, 35.53, 38.48	99" - 100" 2515 MM - 2540 MM
PRC-4805 PRC-4807	LOADER LIFT TRUCK	88,000 115,000	39.917 52.164	17 49, 17 77, 18.43, 19.24, 19.38, 20 28, 21 38, 22.53, 24 05, 25.35, 25.42, 27 49, 28 97, 30 46, 31.94, 32.07, 35.53, 38.48	94.75" - 96" 2407 MM. - 2438 MM.
PRC-5054	SPECIAL PURPOSE	70,000	31,752	16 03, 17 49, 19.24, 21 38, 24.05, 24.51, 25.35, 31 94	70" - 71" 1778 MM - 1803 MM
PRLC-7314	LOADER LIFT TRUCK	91,500 200,000	41.504 90,720	16 03, 17.49, 19.24, 21 38, 24 05, 24 51 25.35, 31 94	95 5" - 104 5" 2426 MM. - 2654 MM
PRC-10254	LIFT TRUCK	353,000	160,000	24.60/21.32	122" 3099 MM.

AXLE SERIES	TYPICAL USAGE ① ③			OVERALL RATIOS	TRACK ⑤ RANGE
	VEHICLE	LBS.	KGS.		
SPRC-1356 SPRC-1357	SPECIAL PURPOSE TRUCK CRANE	65,000 80,000	29.464 36.288	12 76, 13 32, 14.04, 14.80, 15 60, 16.00, 16.65, 17 55, 19.03, 21 00, 22 00, 24.60, 25.92, 28 08, 30.96	85" - 104" 2159 MM. - 2642 MM.
SPRC-1735 SPRC-1736	SPECIAL PURPOSE TRUCK CRANE	85,000 105,000	38.556 47.628	12.76, 13.32, 14 04, 14.80, 15.60, 16.00, 16.55, 17.55, 19.03, 21.00, 22.00, 24.60, 25.92, 28.08, 30.96	85" - 100" 2159 MM. - 2540 MM.
SPRC-1926	SPECIAL PURPOSE TRUCK CRANE	100,000 120,000 110,000 130,000	45,360 54,432 49,896 58,968	12 78, 13.37, 14 10, 14.86, 15.86, 16 76, 18 13, 19 10, 21 15, 23.43, 25.37 16 40, 17 16, 18.09, 19 07, 20 35, 21 51, 23.26, 24 51, 27 13, 30 07, 32 56	86" - 115" 2184 MM. - 2921 MM.
SPRC-1927	LOG HAULER	350,000	158,730	With 0 756 Drop Gear Carrier 9 59, 10 66, 11 24, 11 99, 12 64, 13 71, 15 93, 17 72	90" 2286 MM.
SPRC-4806	SPECIAL PURPOSE TRUCK CRANE	150,000 180,000	68,040 81,647	With 756 Drop Gear Carrier 12 83, 14 55, 16 16, 17 03, 18 18, 19 16, 20 78, 24 24, 26.86 With 1 1 Drop Gear Carrier 16 98, 19 24, 21 38, 22 53, 24 05, 25.35, 27 49, 32 07, 35 53	93" - 116" 2362 MM. - 2946 MM.
EPRC-1357	TRUCK CRANE	120,000	54,432	12 76 13 32, 14 04, 14 80, 15 60, 16 00, 16 65, 17 55, 19 03, 21 00, 22 00, 24 60, 25 92, 28 08, 30.96	85" - 104" 2159 MM. - 2642 MM.
EPRC-1736	TRUCK CRANE	155,000	70,308	12 76, 13 32, 14 04, 14 80, 15 60, 16.00, 16 55, 17 55 19 03 21 00, 22 00, 24 60, 25.92, 28 08 30 96	85" - 100" 2159 MM. - 2540 MM.
EPRC-4806	TRUCK CRANE	240,000	108,863	With 756 Drop Gear Carrier: 12 83, 14 55, 16 16, 17.03, 18 18, 19.16, 20.78, 24 24, 26 86 With 1:1 Drop Gear Carrier 16 98, 19 24, 21 38, 22.53, 24 05, 25 35, 27 49, 32.07, 35 53	93" - 116" 2362 MM. - 2946 MM.

AXLE SERIES	TYPICAL USAGE ①			OVERALL RATIOS	TRACK RANGE
	VEHICLE	LBS.	KGS.		
TA-267	TOW TRACTOR	6,000	2,722	13.57, 15.56, 16.97, 18.70 19.25, 22.00	42" - 60.78" 1067 MM. - 1544 MM.
TA-268	TOW TRACTOR	10,000	4,536	13 57, 15 56, 16 97, 18 70, 19 25, 22 00	48" - 51.5" 1219 MM. - 1308 MM.
TA-274	LIFT TRUCK	25,000	11,340	11.06, 11.66, 14.23, 16.69, 18.31	43.38" - 47.89" 1102 MM - 1216 MM.
TA-362	LIFT TRUCK	29,000	13,154	3.73, 4.10, 4.63, 4.89, 5.29, 5.83 6 17, 6.83, 7.17, 7.80, 8 20	70" 1778 MM.

PSC-824 Series For All-Terrain Cranes



Disc brake version

Drum brake version

Rated Capacity: 27,500 lbs (12,474 Kg)

Carrier: H-140 available ratios — 3.7, 4.111
Optional No-Spin* or Hi Traction differentials

Planetary: Fast planetary 2.6:1 ratio

Overall Axle Ratios: 9.62:1, 10:69:1

Axle Shafts: Double cardon axle shaft assembly

Brakes:

- 20.25 x 4 (514.3 mm x 102 mm) RSA air drum brake with or without parking feature
- Dual 6 piston caliper hydraulic disc brakes

Mounting Centers — 36.62″ (930.1 mm) 60.50″ (1536.7 mm)
Hub Flange to Flange — w/disc brake 90.25″ (2292.4 mm)
w/drum brake 86.00″ (2184.4 mm)
Axle Overall Length — w/disc brake 102.36″ (2600.0 mm)
w/drum brake 97.52″ (2477.0 mm)
Steer Angle — 28°
Tracks — 85.28″ (2166.1 mm), 82.12″ (2085.8 mm)
Load Radius — 26.5″ (673.1 mm), 24.7″ (627.4 mm)
Rim Sizes — 17″ x 25″ (431.8 mm x 635.0 mm),
10″ x 24″ (254 mm x 609.6 mm)

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Rockwell International

Off-Highway Products and Supply Division
Rockwell International Corporation
2135 West Maple Road
Troy, Michigan 48084 U.S.A.

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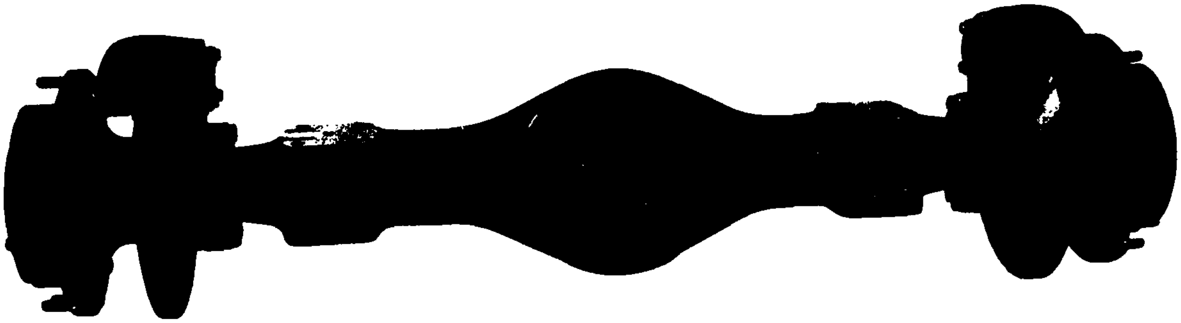
TP-8543 (ISSUED 4-85)

Clark Axles

D-13000
Planetary Drive Axles

D-13000
Planetary Drive Axles



GROSS AXLE CAPACITY RATINGS VARY WITH APPLICATION AND SERVICE.

SPECIFICATIONS AND/OR DESIGNS ARE SUBJECT TO CHANGE WITHOUT NOTICE OR OBLIGATION.

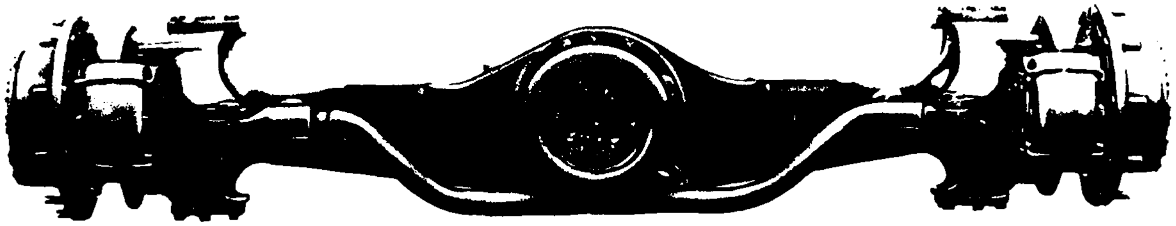
CLARK COMPONENTS COMPANY

BUCHANAN, MICHIGAN U.S.A. 49107

DS-13000
Planetary Drive Steer Axle

CLARK

DS-13000
Planetary Drive Steer Axle



CAPACITY RATINGS VARY WITH APPLICATION AND SERVICE.

CAPACITY DATA FOR SPECIFIC APPLICATIONS FURNISHED ON REQUEST.

SPECIFICATIONS AND/OR DESIGNS ARE SUBJECT TO CHANGE WITHOUT NOTICE OR OBLIGATION.

CLARK Components Division

Buchanan, Michigan U.S.A. 49107

Spicer Axles

SPICER®

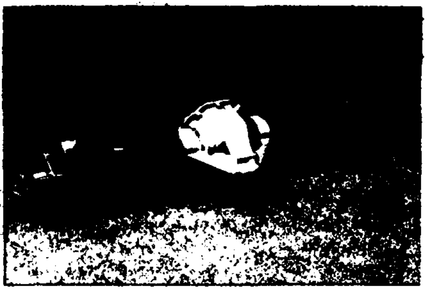
DANA

THE SYSTEM THAT WORKS

Spicer Heavy Axle Division's Sales-Engineers understand complete industrial vehicular drivetrain systems — it's part of "The Spicer Knowledge Package" of Spicer clutches, transmissions, u-joints and axles that we share with customers in meeting the challenge of new product design requirements and improving existing industrial drivetrain systems.

The emphasis throughout the Spicer Heavy Axle Product Engineering Group is flexibility — your demanding specifications and our wide variety of Spicer designs and options make a system that works best for you. And our Engineering Group and nine Spicer axle manufacturing facilities realize the importance of quick response and product turn-around time in the industrial vehicular markets.

Check the specifications and Spicer Axle features — challenge us with your custom or special applications — then let's work together on a Spicer Axle or Spicer System that's right for you.



SPICER MODEL 18 LIGHT DUTY

SPICER [illegible] GEARING

SPICER MODEL 70 HEAVY DUTY

Rigid Drive Axles

Axle Model No.	Nominal G.A.W. Rating (Lbs.)	Available Ratio Range	Available Track Range (In.)	Min. Rim Size (In.)	Brake Type And Size	Diff. Ring Gear Diameter (In.)
12	1,200	5.17 to 12.25	24.5 to 43.2	8.50	Mech. or Hyd. 7.00" Dia. × 1.75"	6.375
18	1,800	5.17 to 12.25	26.4 to 50.6	8.50	Mech. or Hyd. 7.00" Dia. × 1.75"	7.375
GT-20	1,800	15.50 to 30.00	26.4 to 50.6	8.50	Mech. or Hyd. 7.00" Dia. × 1.75"	7.375
30	3,000	3.07 to 5.38	42.2 to 58.2	14.00	Hyd. 11.00" Dia. × 2.00" Std. Brake & Drum	7.125
44	3,300	3.07 to 5.89	42.2 to 58.2	14.00	Hyd. 11.00" Dia. × 2.00" Std. Brake & Drum	8.500
60-SF	4,200	3.54 to 7.17	42.2 to 58.2	15.00	Hyd. 12.00" Dia. × 2.00" Std. Brake & Drum	9.750
60-FF	5,900	3.54 to 7.17	46.0 to 66.0	16.50	Hyd. 12.00" Dia. × 2.50" Std. Brake & Drum	9.750
70	7,500	3.73 to 7.17	60.0 to 70.0	16.50	Hyd. 13.00" Dia. × 2.50" Std. Brake & Drum	10.500
70-HD	10,000	3.73 to 7.17	54.8 to 70.0	16.50	Hyd. 14.125 "Dia. × 3.00" Std. Brake & Drum	10.500
D-135S	13,500	5.29 to 7.17	Approx. 69.50 W/Duals	20.00	Disc 2.8" Dia Dual Piston	12.500 or 13.000
F-155S	15,500	4.78 to 7.17	Approx. 69.50 W/Duals	20.00	Disc 2.8" Dia. Dual Piston	14.250
F-170S	17,000	4.78 to 7.17	Approx. 70.00 W/Duals	20.00	Air 16.50" Dia. × 6.0" Hydraulic Disc	14.250
G-175S	17,500	3.54 to 8.17	Approx. 71.00 W/Duals	20.00	Air 16.50" Dia. × 8.0" Hydraulic Disc	16.000
G-175T	17,500	4.56 to 7.17	Approx. 71.00 W/Duals	20.00	Air 16.50" Dia. × 6.0" Hydraulic Disc	15.750
M-190S	19,000	3.54 to 8.17	Approx. 72.00 W/Duals	20.00	Air 16.50" Dia. × 7.0" Hydraulic Disc	17.000
M-190T	19,000	3.70 to 7.17	Approx. 72.00 W/Duals	20.00	Air 16.50" Dia × 7.0" Hydraulic Disc	17.000
M-220S	22,000	3.54 to 8.17	Approx. 72.00 W/Duals	20.00	Air 16.50" Dia × 7.0"	17.000
M-220T	22,000	3.70 to 7.17	Approx. 72.00 W/Duals	20.00	Air 16.50" Dia. × 7.0"	17.000
W-230S	23,000	3.54 to 7.17	Approx. 72.00 W/Duals	20.00	*	18.000

* Contact Spicer

Steering Non-Drive Axles

Axle Model No.	Nominal G.A.W. Rating (Lbs.)	Available Ratio Range	Available Track Range (In.)	Min. Rim Size (In.)	Brake Type And Size	Diff. Ring Gear Diameter (In.)
44-DF	3,300	N/A	**	15.00 16.50	Disc 5-Bolt (11.72"Rotor) Disc 8-Bolt (12.50"Rotor)	N/A
70-DF	5,700	N/A	**	16.50	Disc 12.88" Dia.	N/A
I-60	6,000	N/A	77.20 to 82.90	20.00	Air 15.00" Dia. × 3.5" Hydraulic Disc	N/A
I-75	7,500	N/A	76.70 to 81.60	20.00	Air 15.00" Dia. × 3.5" Hydraulic Disc	N/A
I-90	9,000	N/A	79.40 to 81.40	20.00	Air 15.00" Dia. × 4.0" Hydraulic Disc	N/A
I-108	10,800	N/A	79.30 to 81.20	20.00	Air 15.00" Dia. × 4.0" Hydraulic Disc	N/A
I-120	12,000	N/A	79.10 to 81.60	20.00	Air 15.00" Dia. × 4.0" 16.50" Dia. × 5.0" Hydraulic Disc	N/A

** Variable

Steering Drive Axles

Axle Model No.	Nominal G.A.W. Rating (Lbs.)	Available Ratio Range	Available Track Range (In.)	Min. Rim Size (In.)	Brake Type And Size	Diff. Ring Gear Diameter (In.)
44-F	3,300	3.07 to 5.89	38.6 to 69.2	15.00 16.50	Disc 5-Bolt (11.72"Rotor) Disc 8-Bolt (12.50"Rotor)	8.500
60-F	4,300	3.54 to 7.17	44.7 to 74.0	16.50	Disc 12.88" Dia.	9.750
70-F	5,700	3.73 to 7.17	51.1 to 79.0	16.50	Disc 12.88" Dia.	10.500
70-HD-F	7,000	3.73 to 7.17	**	20.00	Air 15.00" Dia. × 4.0" Hydraulic *	10.500
S-9000	9,000	5.29 to 7.17	63.9 to 90.30	20.00	Air 15.00" Dia. × 4.0" Hydraulic *	12.500 or 13.000

* Contact Spicer
** Variable

Tandem Axles

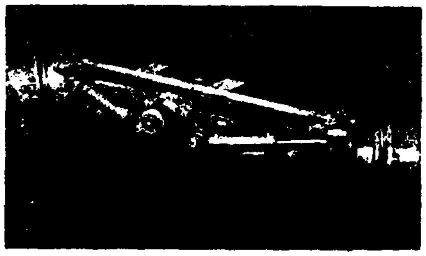
Axle Model No.	Nominal G.A.W Rating (Lbs.)	Available Ratio Range	Available Track Range (In.)	Min. Rim Size (In.)	Brake Type And Size	Diff. Ring Gear Diameter (In.)
G-340S	34,000	4.10 to 8.17	Approx. 72 W/Duals	20.00	Air 16.50" Dia. × 7.0" Disc 2.88" Dia. Dual Piston	18.00
G-380S	38,000	4.10 to 8.17	Approx. 72 W/Duals	20.00	Air 16.50" Dia. × 7.0"	18.00
G-400S	40,000	3.54 to 8.17	Approx. 72 W/Duals	20.00	Air 16.50" Dia. × 7.0"	18.00
M-460S	46,000	3.54 to 7.17	Approx. 72 W/Duals	20.00	Air 16.50" Dia. × 7.0"	18.00

SPICER®

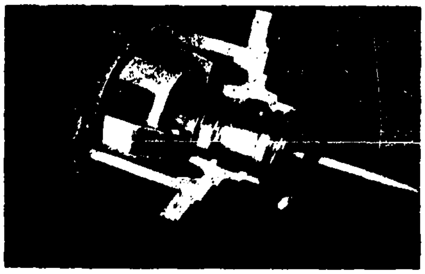
DANA

SPICER FEATURES*

- **Spicer CAD-CAM Systems**
- **Spicer Hypoid Gearing and Spiral-Bevel Gearing**
- **Patented-Pressurized Lube System** (No. 4,274,298)
- **Parts Interchangeability**
- **Precision Forged Differential Gearing**
- **Rolled Involute Splines**
- **One-Piece Carrier Designs**
- **Cast-In Oil Channels**
- **Large Planetary-Sun Gears**
- **Latest Fastener Technology**
- **HSLA (High Strength, Low Alloy) Steel Housings**
- **Integral Carrier Supports**
- **Induction Heat-Treated Spindles**
- **Interchangeable Suspension Hubs, Drums or Discs and Brakes**
- **Variable Spring Seats**
- **Optional Carrier Placement**
- **Optional Semi-Float or Full Float Designs**
- **Optional Planetary Wheel-Ends**



SPICER 60° STEER-PLANETARY



SPICER PLANETARY WHEEL-END

* APPLICATION POLICY:

Spicer axle capacity ratings, features and specifications vary depending upon axle model, type of application and type of service. Application approvals must be obtained from Spicer Heavy Axle Industrial Engineering Department. Spicer specifications are subject to change without notice.

Spicer Heavy Axle Division
Dana Corporation
P.O. Box 2229
Fort Wayne, IN 46801

Independent Carriers

Axle Model No.	Nominal G.A.W. Rating (Lbs.)	Available Ratio Range	Typical Track Width (In.)	Min. Rim Size (In.)	Brake Type And Size	Diff. Ring Gear Diameter (In.)
18-IS	N/A	5.17 to 12.25	N/A	N/A	N/A	7.375
QT-20-IS	N/A	15.50 to 30.00	N/A	N/A	N/A	7.375
44-IC	N/A	2.73 to 5.89	N/A	N/A	N/A	6.500
70-IC	N/A	5.43 to 7.20	N/A	N/A	N/A	12.250
R30-IC	N/A	5.29 to 7.17	N/A	N/A	N/A	12.500 or 13.000

Rigid Drive Axles-Double Reduction

Axle Model No.	Nominal G.A.W. Rating (Lbs.)	Available Ratio Range	Typical Track Width (In.)	Min. Rim Size (In.)	Brake Type And Size	Diff. Ring Gear Diameter (In.)
P-15R	8,000	14.00 to 20.70	34.57	6.00	Hyd. 7.09" Dia. × 1.57"	*
P-16R	15,000	10.00 to 24.00	33.86	8.00	Hyd. 7.87" Dia. × 1.57"	7.087
P-20R	18,000	8.00 to 27.00	33.88	10.00	Hyd. 10.51" Dia. × 2.52"	9.843

Rigid Drive Axles-Planetary

Axle Model No.	Nominal G.A.W. Rating (Lbs.)	Available Ratio Range	Typical Track Width (In.)	Min. Rim Size (In.)	Brake Type And Size	Diff. Ring Gear Diameter (In.)
PR-1100	10,000 to 22,000	11.57 to 30.11	40.00 to 61.25	20.00**	Hydraulic Drum 15.75" Dia. × 3.15" Disc 15.25" Dia.	10.500
PR-1300	27,000	16.69 to 30.19	44.80 to 81.25	20.00**	Hydraulic Drum 15.75" Dia. × 3.15" Disc 15.25" Dia.	12.500 or 13.000
PR-1800	30,000	18.25 to 35.24	[illegible]	22.00	Air 17.25" Dia. × 4.00" Disc	*
P-40R	29,700	[illegible]	[illegible]	15.00	Hyd. 12.40" Dia. × 3.15"	8.921
P-61R	39,700	[illegible]	[illegible]	[illegible]	Hyd. 12.40" Dia. × 3.15"	[illegible]
P-61/81R	28,600	14.00 to [illegible]	58.89	20.00	Disc	12.008
P-62R	14,200	15.50 to 27.32	[illegible]	15.00	Hyd. 12.80" Dia. × 3.15"	9.961
P-63R	22,000	14.00 to [illegible]	[illegible]	20.00	Air/Hydraulic 15.75" Dia. × 6.30" or 15.75" Dia. × 4.72"	12.008
P-80R	12,200	4.00 to 8.00	[illegible]	[illegible]	Hyd. 12.80" Dia. × 4.72"	8.614
P-97R	22,000	8.70 to 16.40	79.53	20.00	Air 16.14" Dia. × 7.87"	12.598
P-98R	22,300	3.26 to 5.28	73.39	19.50	Air 15.00" Dia. × 7.00"	12.330
P-99R	28,600	6.00 to 10.00	71.81	20.00	Air 16.14" Dia. × 7.87"	12.205
P-99RB	24,300	8.00 to 11.00	71.81	20.00	Air 16.14" Dia. × 7.87"	12.476
P-100R	32,500	16.00 to 27.00	[illegible]	20.00	Mech. Parking Hyd. 15.75" Dia. × 3.15"	14.961
P-102R	28,500	6.00 to 15.00	79.72	20.00	Air 16.14" Dia. × 7.87"	12.598
P-103R	28,600 to 90,000	8.75 to 21.00	72.95 to 81.10	20.00	Air/Hydraulic 16.69" Dia. × 4.72" Disc	12.598
P-120R	24,300	[illegible] to 11.77	72.68	20.00	Air 16.14" Dia. × 7.09	13.541
P-150R	60,900	18.00 to 22.00	72.05	24.00	Hyd. 17.32" Dia. × 5.51"	16.908
P-160R	18,200	5.60 to 6.70	56.93	20.00	Air 15.00" Dia. × 7.00"	14.961
P-180R	55,000	11.00 to 20.00	78.54	24.00	Air/Hydraulic 19.69" Dia. × 4.72"	16.142
P-200R	70,500 to 127,000	13.00 to 25.00	90.55 to 95.51	24.00	Air (Disc) 19.69" Dia. × 7.87"	18.307
P-203R	70,500	13.00 to 25.00	88.58	24.00	Disc	18.307
P-280R	88,200	11.00 to 25.00	100.79	25.00	Air 19.69" Dia. × 7.87" or Disc	21.654
P-281R	277,800	11.00 to 25.00	100.79	25.00	Air (Twin) 19.69" Dia. × 5.12"	21.654
P-300R	98,200	11.00 to 16.50	105.12	33.00	Air 25.98" Dia. × 8.66" or Disc	21.654

Steering Drive Axles-Planetary

Axle Model No.	Nominal G.A.W. Rating (Lbs.)	Available Ratio Range	Typical Track Width (In.)	Min. Rim Size (In.)	Brake Type And Size	Diff. Ring Gear Diameter (In.)
PS-1100	10,000 to [illegible]	11.57 to 30.11	60.00 to 81.25	20.00**	Hydraulic Drum 15.75" Dia. × 3.15" Disc 15.25" Dia.	10.500
PS-1300	18,000	16.69 to 30.19	63.00 to 81.25	20.00**	Hydraulic Drum 15.75" Dia. × 3.15" Disc 15.25" Dia.	12.500 or 13.00
PS-1800	28,000	18.24 to 35.24	65.00 to 89.00	22.00	Air 17.25" Dia. × 4.00" Disc	*
P-62S	14,200	15.50 to 27.32	88.39	15.00	Hyd. 12.80" Dia. × 3.15"	9.961
P-63S	22,000	14.00 to 23.00	79.13	20.00	Air/Hydraulic 15.75" Dia. × 6.30" or 15.75" Dia. × 4.72"	12.008
P-99S	20,000	6.00 to 10.00	71.81	20.00	Air 16.14" Dia. × 7.87"	12.205
P-102S	28,600	6.00 to 18.00	79.72	20.00	Air 16.14" Dia. × 7.87"	12.598
P-103S	26,600	11.00 to 20.00	81.10	24.00	Air/Hydraulic 19.69" Dia. × 4.72"	12.598
P-150S	30,400	18.00 to 22.00	72.05	24.00	Hyd. 17.32" Dia. × 3.54"	16.908
P-180S	40,000	11.00 to 20.00	78.54	24.00	Air/Hydraulic 19.69" Dia. × 4.72"	16.142

Tandem Axles-Planetary

Axle Model No.	Nominal G.A.W. Rating (Lbs.)	Available Ratio Range	Typical Track Width (In.)	Min. Rim Size (In.)	Brake Type And Size	Diff. Ring Gear Diameter (In.)
P-97T	44,000	8.70 to 16.40	79.53	20.00	Air 16.14" Dia. × 7.87"	12.598
P-98T	44,600	3.26 to 5.28	73.39	19.50	Air 15.00" Dia. × 7.00"	12.330
P-99T	57,300	6.00 to 10.00	71.81	20.00	Air 16.14" Dia. × 7.87"	12.205
P-103T	57,300	11.00 to 20.00	81.10	24.00	Air/Hydraulic 19.69" Dia. × 4.72"	12.598

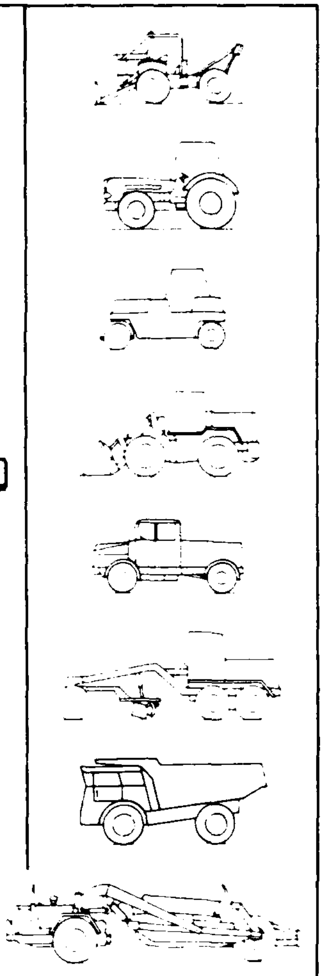
*** Contact Spicer ** 15.00" Slip Ring Hub Optional**

ZF Axles

ZF Rigid Axles

for construction machines and heavy duty commercial vehicles

Series	Type	Total ratio min. – max.	max. Axle load in t for application in construction machines	max. Axle load in t for application in heavy duty commercial vehicles
AP 300 Series ③	AP 315	7 33 – 22 20	1.7	2.1
	AP 325	9 95 – 30 13	2 3	2.8
	AP 345	9.30 – 24 66	3 3	4.1
	AP 355	9 30 – 24 66	4.2	5.2
	AP 365 (AP 5)	9 85 – 39.03	5 3	6.6
	AP 375 (AP 5)	9 85 – 39 03	7 0	8.7
AP 400 Series ③	AP 407 (AP 7)	9 85 – 45.74	9 5	11.8
	AP 409 (AP 9)	9.85 – 45 74	12 0	15.0
	AP 411 (AP 11)	9 85 – 45 74	14.2	17.6
	AP 415 (AP 15)	9.85 – 45.74	17.5	21.7
	AP 417 (AP 17)	9 85 – 45.74	20 6	25.5
	AP 420 (AP 20)	9.85 – 45.74	24 4	30.2
	AP 425 (AP 26)	9.85 – 28.21	30.3	37 6
	AP 430 ① (AP 30)	11.70 – 27 79	36.0	44.6
	AP 440 ① (AP 40)	9.85 – 28.21	48 4	60.0



① in development

③ with wet disc brakes integrated in the wheel head

The AP 300 series is also supplied with a directly attached powershiftable axle transfer gearbox with a flange-mounted hydromotor.

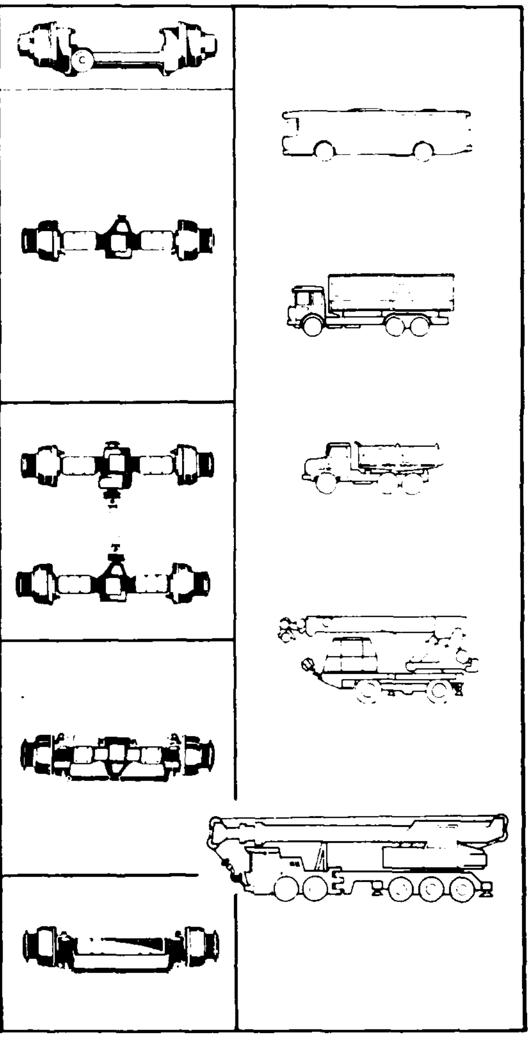
All rigid axles are available with an optional ZF multi-disc self-locking differential (DL) or a ZF gear self-locking differential (DV).

Type in (   ) = present series for construction machines and heavy duty commercial vehicles

ZF Axles
for commercial vehicles and mobile cranes

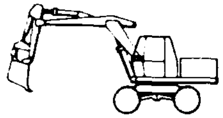
	Type	Total ratio min. – max.	dyn. Axle load in t	static. Axle load in t
Rigid axles	AV 130	4.30 – 6.32	13	
	A 130	3.23 – 6.43	13	
	AP 10500	5.17 – 12.92	12	
	AP · B 35	6.85 – 34.48	13	35
	AP · B 50	6.85 – 34.48	18	50
Tandem axles	APD 20000	5.17 – 12.22	24	
	APD · B 70	6.85 – 16.21	30	70
	APD · B 100	6.85 – 16.21	36	100
Steering axles	APL 7500	5.18 – 13.75	7.5	
	APL · B 25	6.88 – 29.47	10	25
	APL · B 35	6.85 – 34.48	12	35
non-driven Steering axles	ANL · B 25	–	10	25
	ANL · B 35	–	12	35

dyn. Axle load in t
10
20
30
static. Axle load in t
20
40
60
80
100
120



ZF Axles
for excavators

	Type	Total ratio min. – max.	dyn. Axle load in t	static Axle load in t
Rigid axles ③	AP · B 345	9.42 – 24.66	5	12
	AP · B 355 (AP · B 22)	8.96 – 31.93	8	20
	AP · B 365 ① (AP · B 23)	8.06 – 32.10	10	30
	AP · B 375 ① (AP · B 24)	6.88 – 28.18	12	40
Steering axles ③	APL · B 345	9.42 – 24.66	5	12
	APL · B 355 (APL · B 22)	8.96 – 31.33	8	20
	APL · B 365 ① (APL · B 23)	8.06 – 32.10	10	30
	APL · B 375 ① (APL · B 24)	6.88 – 28.18	12	40



① in development

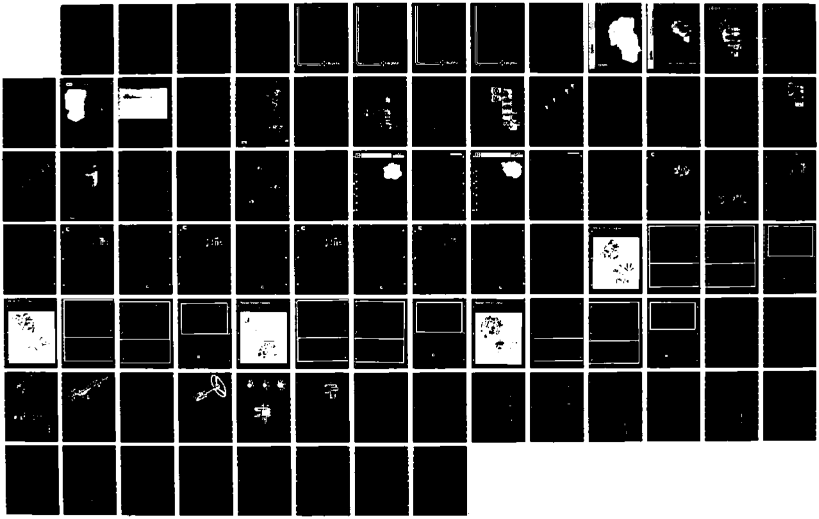
③ The types AP · B 300 and APL · B 300 have wet disc brakes integrated in the wheel head

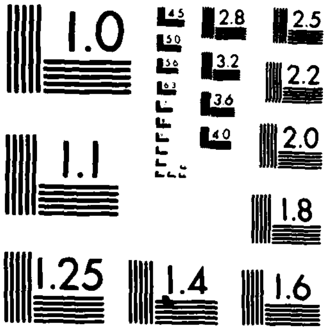
Type in ( ) = present series for excavators

All rigid axles are also supplied with a directly attached powershiftable axle transfer gearbox with a flange-mounted hydromotor

AD-A170 798 FEASIBILITY OF ROUGH TERRAIN FORKLIFT TRUCKS WITH A ROAD SPEED CAPABILITY OF 45 MPH(U) LITTLE (ARTHUR D) INC CAMBRIDGE MA J S HOWLAND MAY 86 ADL-54964 3/3

UNCLASSIFIED DAAK70-85-C-0112 F/G 13/6 NL




1.0
4.5
5.0
5.6
6.3
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

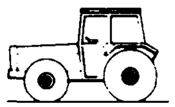
ZF Steering Axles
for tractors

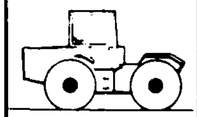
static Axle load in t ✱✱✱

] = including front axle ballast

[ ] with front loader operation

	Type	Total ratio min. – max.	Tractor power kW✱✱✱	static Axle load in t ✱✱✱ including front axle ballast	with front loader operation
Narrow track version	**APL 305**	7.46 – 14.76	30	1.2	3.0
	APL 310	7.46 – 14.76	45	1.6	3.5
Standard version	**APL 315**	7.34 – 17.55	45	1.9	3.7
	APL 325	9.96 – 23.83	60	2.3	5.0
	APL 335	9.96 – 23.83	75	2.8	5.5
	APL 345	10.02 – 19.86	90	3.0	6.0
	APL 355	10.02 – 21.60	110	3.4	6.0
	APL 365	9.96 – 22.73	135	3.8	6.5
	APL 375	9.96 – 22.73	170	5.0	7.0
	APL 6	17.49 – 37.44	220	7.0	
	APL 8	20.85 – 44.64	290	11.0	

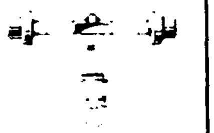
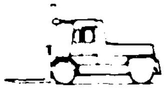




✱✱✱approx value

The steering axles are available, on request, with a ZF multi-disc self locking differential and with brakes

ZF Rigid Axles
for forklift trucks

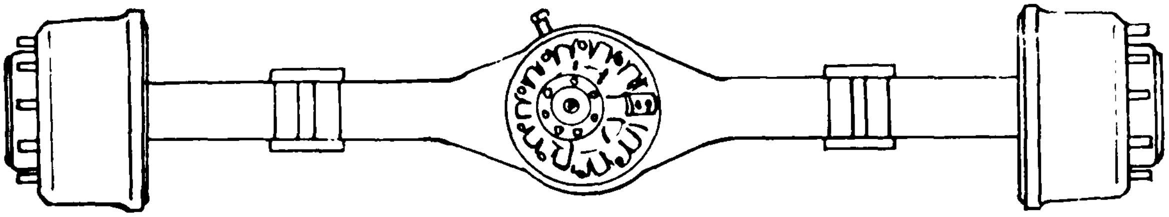
Type	Total ratio mechanical min. – max.	Total ratio hydrostatic min. – max.	Lifting capacity in t (depending on application)	Axle load in t (depending on tyre size and application)		
AP · ST 12 **(AP · B 23)** ④	6.02 – 25.88	6.08 – 82.82	7.5	16		
AP · ST 14 **(AP · B 24)** ④	6.88 – 29.47	6.88 – 94.30	8.5	19		
AP · ST 20 **(AP · B 35)** ④	6.85 – 31.83	6.85 – 101.86	12	25		
AP · ST 25 **(AP 9)**	6.85 – 31.83		15	32		
AP · ST 35 **(AP 15)**	6.85 – 31.83		22	48		
AP · ST 40 **(AP 17)**	8.06 – 37.44		24	52		
AP · ST 50 **(AP 20)**	9.61 – 44.64		30	67		
AP · ST 65 **(AP 30)**	9.58 – 27.12		40	87		

④ *optionally available with axle transfer gearbox and attached hydrostatic unit*

Apart from the axle beams, axle types AP-ST are the same as those used in excavators, construction machines and heavy duty commercial vehicles, shown in ( ).

SOMA Axles

3 MR/F
PLANETARY DRIVE AXLE



GENERAL SPECIFICATIONS		
NOMINAL LOAD RATING	:	15,000 LBS.
TORQUE CAPACITY	:	(@ Diff. Centerline) 45,000 IN.-LBS.
DRY WEIGHT	:	650 - 900 LBS
LUBRICANT	:	80w90 GEAR LUBE (MIL L2105C)
LUBE CAPACITY	:	7 - 13 QUARTS
BRAKE OPTIONS	:	AIR, HYDRAULIC, DISC

DIFFERENTIAL CARRIER	
TYPE:	SPIRAL BEVEL
SIZE:	7.8 INCHES DIAMETER
OPTIONS:	STANDARD, LIMITED SLIP
	DIFF. LOCK (HYDRAULIC OR
	AIR ACTUATED)
INPUT FLANGES:	MECHANICS, SPICER

PLANETARY WHEEL ENDS	
RATIO OPTIONS:	3.5:1, 5.6:1
WHEEL MOUNTING:	¾-16 UNF STUDS
OPTIONS:	(10) STUDS ON 13.18 DIA B.C.
	(FOR 20 IN. & LARGER WHEELS)
	(8) STUDS ON 10.83 DIA. B.C.
	(FOR 15 INCH & LARGER WHEELS)

AVAILABLE RATIOS

GEAR SET	DIFFERENTIAL RATIO	PLANETARY 3.5	PLANETARY 5.6	GEAR SET	DIFFERENTIAL RATIO	PLANETARY 3.5	PLANETARY 5.6
11 x 27	2.45	8.58	13.72	7 x 35	5.0	17.50	28.0
12 x 27	2.25	7.88	12.60	8 x 35	4.38	15.33	24.53
13 x 27	2.08	7.28	12.60	8 x 35	4.38	15.33	24.53
14 x 27	1.93	6.76	10.81	10 x 35	3.50	12.25	19.60
15 x 27	1.80	6.30	10.08	11 x 35	3.18	11.13	17.81
16 x 27	1.69	5.92	9.47	12 x 35	2.92	10.22	16.35
17 x 27	1.59	5.57	8.90	13 x 35	2.69	9.42	15.06

- Dimensions to suit vehicle requirements.
- Available with Standard Mounting Pad Configuration or Trunnion Mount Feature.

NOTE: **(1)** Torque values given for axles may be increased or decreased depending on type of application.

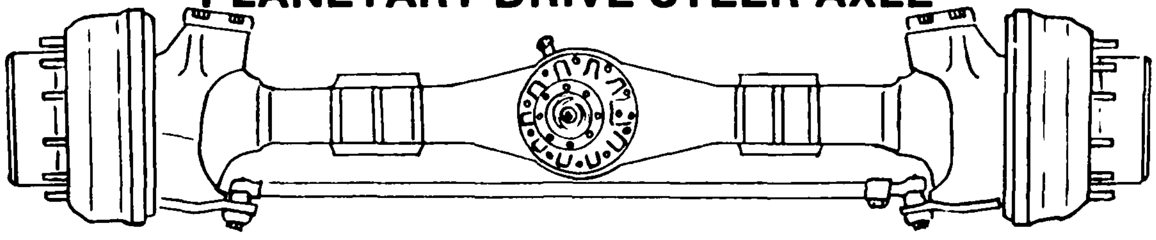
(2) Approved loads depend upon actual track and mounting centers desired.

Product information given is representative and varies with each application. Please consult us for specific information.

SOMA
OF AMERICA, INC.

P O Box 9368 Briarfield Station
Hampton, Virginia 23670
Telephone (804) 827-0310 Telex 82-3400

3 MRDi/F
PLANETARY DRIVE STEER AXLE



GENERAL SPECIFICATIONS		
NOMINAL LOAD RATING	:	15,000 LBS.
TORQUE CAPACITY	:	(@ Diff. Centerline) 45,000 IN.-LBS.
DRY WEIGHT	:	650 - 900 LBS.
LUBRICANT	:	80w90 GEAR LUBE (MIL L2105C)
LUBE CAPACITY	:	7 - 13 QUARTS
BRAKE OPTIONS	:	AIR, HYDRAULIC, DISC

DIFFERENTIAL CARRIER	
TYPE:	SPIRAL BEVEL
SIZE:	7.8 INCHES DIAMETER
OPTIONS:	STANDARD, LIMITED SLIP
	DIFF. LOCK (HYDRAULIC OR
	AIR ACTUATED)
INPUT FLANGES:	MECHANICS, SPICER

PLANETARY WHEEL ENDS	
RATIO OPTIONS:	3.5:1, 5.6:1
WHEEL MOUNTING:	¾-16 UNF STUDS
OPTIONS:	(10) STUDS ON 13.18 DIA B.C.
	(FOR 20 IN. & LARGER WHEELS)
	(8) STUDS ON 10.83 DIA. B.C.
	(FOR 15 INCH & LARGER WHEELS)

AVAILABLE RATIOS

GEAR SET	DIFFERENTIAL RATIO	PLANETARY		GEAR SET	DIFFERENTIAL RATIO	PLANETARY	
		3.5	5.6			3.5	5.6
11 x 27	2.45	8.58	13.72	7 x 35	5.0	17.50	28.0
12 x 27	2.25	7.88	12.60	8 x 35	4.38	15.33	24.53
13 x 27	2.08	7.28	12.60	8 x 35	4.38	15.33	24.53
14 x 27	1.93	6.76	10.81	10 x 35	3.50	12.25	19.60
15 x 27	1.80	6.30	10.08	11 x 35	3.18	11.13	17.81
16 x 27	1.69	5.92	9.47	12 x 35	2.92	10.22	16.35
17 x 27	1.59	5.57	8.90	13 x 35	2.69	9.42	15.06

- Dimensions to suit vehicle requirements.
- Available with Standard Mounting Pad Configuration or Trunnion Mount Feature.
- Steering Cylinder mounts on front or back of axle.
- With up to 35° steer angle

NOTE: **(1)** Torque values given for axles may be increased or decreased depending on type of application.

(2) Approved loads depend upon actual track and mounting centers desired.

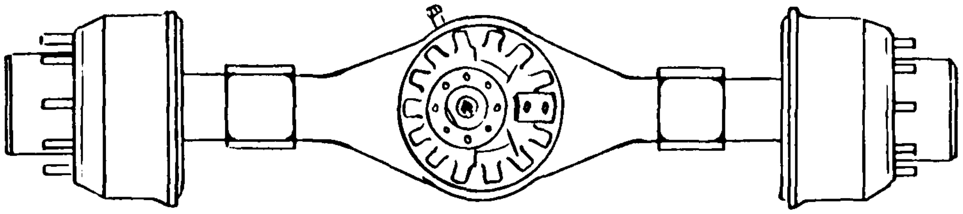
Product information given is representative and varies with each application. Please consult us for specific information.

SOMA® OF AMERICA, INC.

P.O. Box 9368 Briarfield Station
Hampton, Virginia 23670
Telephone (804) 827-0310 Telex 82-3400

5 MR/F

PLANETARY DRIVE AXLE



GENERAL SPECIFICATIONS		
NOMINAL LOAD RATING	:	30,000 LBS.
TORQUE CAPACITY	:	(@ Diff. Centerline) 90,000 IN.-LBS.
DRY WEIGHT	:	800 - 1400 LBS.
LUBRICANT	:	80w90 GEAR LUBE (MIL L2105C)
LUBE CAPACITY	:	14 - 20 QUARTS
BRAKE OPTIONS	:	AIR, HYDRAULIC, DISC

DIFFERENTIAL CARRIER	
TYPE:	SPIRAL BEVEL
SIZE:	10.75 INCHES DIAMETER
OPTIONS:	STANDARD, LIMITED SLIP,
	DIFF. LOCK (HYDRAULIC OR
	AIR ACTUATED)
INPUT FLANGES:	MECHANICS, SPICER

PLANETARY WHEEL ENDS	
RATIO OPTIONS:	3.5:1, 5.6:1
WHEEL MOUNTING:	¾-16 UNF STUDS
OPTIONS:	(10) STUDS ON 13.18 DIA. B.C.
	(FOR 20 IN. & LARGER WHEELS)
	(8) STUDS ON 10.83 DIA. B.C.
	(FOR 15 INCH & LARGER WHEELS)

AVAILABLE RATIOS

GEAR SET	DIFFERENTIAL RATIO	PLANETARY		GEAR SET	DIFFERENTIAL RATIO	PLANETARY	
		3.5	5.6			3.5	5.6
11 x 27	2.45	8.58	13.72	20 x 27	1.35	4.72	7.56
12 x 27	2.25	7.88	12.60	7 x 35	5.00	17.50	28.0
13 x 27	2.08	7.28	11.65	8 x 35	4.38	15.33	24.53
14 x 27	1.93	6.76	10.81	9 x 35	3.89	13.62	21.78
15 x 27	1.80	6.30	10.08	10 x 35	3.50	12.25	19.60
16 x 27	1.69	5.92	9.47	11 x 35	3.18	11.13	17.81
17 x 27	1.54	5.57	8.90	12 x 35	2.92	10.22	16.35
18 x 27	1.50	5.25	8.40	13 x 35	2.69	9.42	15.06
19 x 27	1.42	4.97	7.95				

- Dimensions to suit vehicle requirements.

NOTE: **(1)** Torque values given for axles may be increased or decreased depending on type of application.

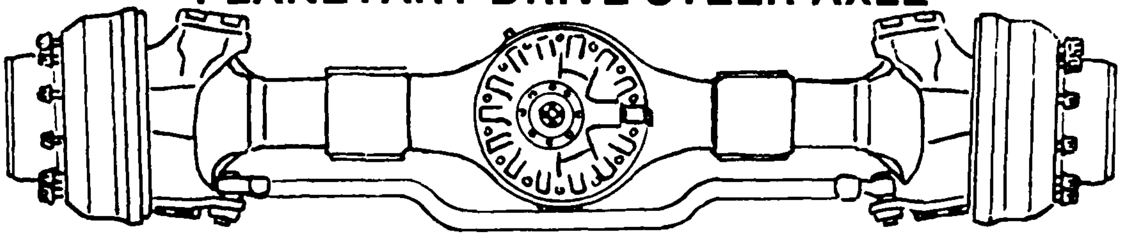
(2) Approved loads depend upon actual track and mounting centers desired.

Product information given is representative and varies with each application. Please consult us for specific information.

SOMA®
OF AMERICA, INC.
P.O. Box 9368 Briarfield Station
Hampton, Virginia 23670
Telephone (804) 827-0310 Telex 82-3400

5 MRDi/F

PLANETARY DRIVE STEER AXLE



GENERAL SPECIFICATIONS		
NOMINAL LOAD RATING	:	30,000 LBS.
TORQUE CAPACITY	:	(@ Diff. Centerline) 90,000 IN.-LBS.
DRY WEIGHT	:	800 - 1400 LBS.
LUBRICANT	:	80w90 GEAR LUBE (MIL L2105C)
LUBE CAPACITY	:	14 - 20 QUARTS
BRAKE OPTIONS	:	AIR, HYDRAULIC, DISC

DIFFERENTIAL CARRIER	
TYPE:	SPIRAL BEVEL
SIZE:	10.75 INCHES DIAMETER
OPTIONS:	STANDARD, LIMITED SLIP,
	DIFF. LOCK (HYDRAULIC OR
	AIR ACTUATED)
INPUT FLANGES:	MECHANICS, SPICER

PLANETARY WHEEL ENDS	
RATIO OPTIONS:	3.5:1, 5.6:1
WHEEL MOUNTING:	(10)¾-16UNF ON 13.18 DIA B.C.
	(FOR 20 INCH AND LARGER WHEELS)

AVAILABLE RATIOS

GEAR SET	DIFFERENTIAL RATIO	PLANETARY		GEAR SET	DIFFERENTIAL RATIO	PLANETARY	
		3.5	5.6			3.5	5.6
11 x 27	2.45	8.58	13.72	20 x 27	1.35	4.72	7.56
12 x 27	2.25	7.88	12.60	7 x 35	5.00	17.50	28.0
13 x 27	2.08	7.28	11.65	8 x 35	4.38	15.33	24.53
14 x 27	1.93	6.76	10.81	9 x 35	3.89	13.62	21.78
15 x 27	1.80	6.30	10.08	10 x 35	3.50	12.25	19.60
16 x 27	1.69	5.92	9.47	11 x 35	3.18	11.13	17.81
17 x 27	1.54	5.57	8.90	12 x 35	2.92	10.22	16.35
18 x 27	1.50	5.25	8.40	13 x 35	2.69	9.42	15.06
19 x 27	1.42	4.97	7.95				

- Steering Cylinder Mounts on front or back of axle.
- With up to 35° steer angle.
- Dimensions to suit vehicle requirements.

NOTE: **(1)** Torque values given for axles may be increased or decreased depending on type of application.

(2) Approved loads depend upon actual track and mounting centers desired.

Product information given is representative and varies with each application. Please consult us for specific information.

SOMA
OF AMERICA, INC.
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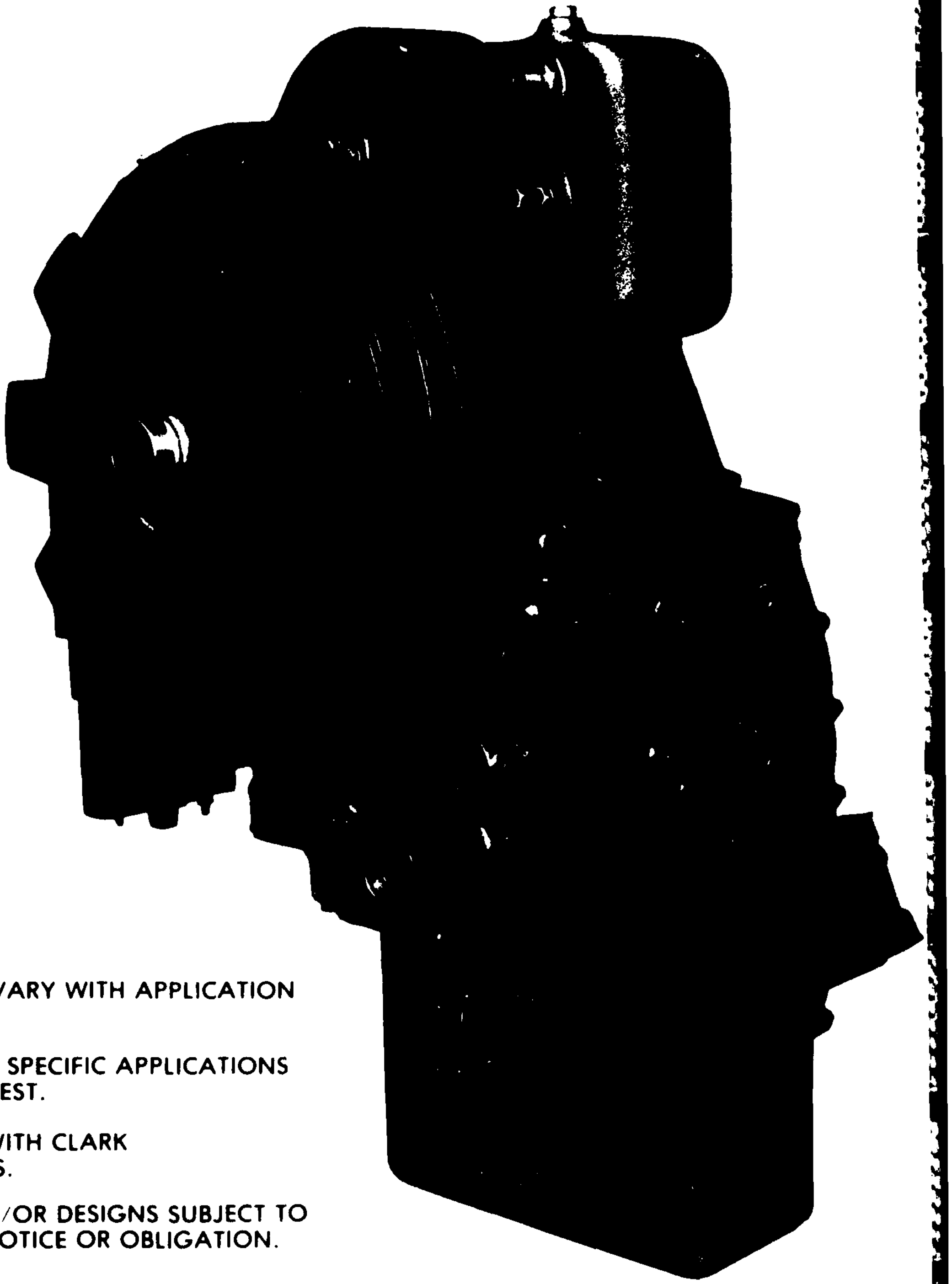
Clark Power Shift Transmissions

18000 Series
Long Drop
Full Powershift Transmission

18000 Series
Long Drop Full Powershift
Transmission

CLARK



CAPACITY RATINGS VARY WITH APPLICATION AND SERVICE.

CAPACITY DATA FOR SPECIFIC APPLICATIONS FURNISHED ON REQUEST.

DESIGNED FOR USE WITH CLARK TORQUE CONVERTERS.

SPECIFICATIONS AND/OR DESIGNS SUBJECT TO CHANGE WITHOUT NOTICE OR OBLIGATION.

CLARK **Components Division**
Buchanan, Michigan U.S.A. 49107

D-28

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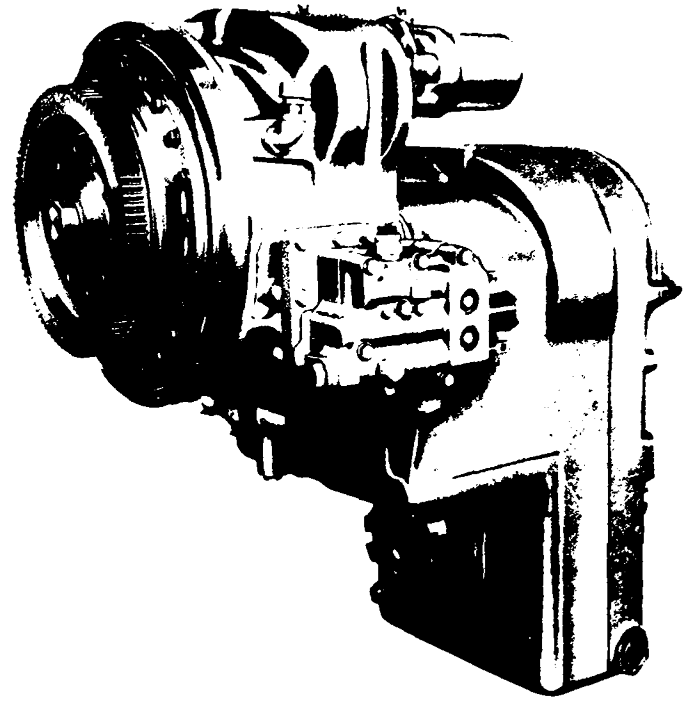
32000 Series
Long Drop Powershift Transmission

Six Speeds Forward and 3 Speeds Reverse

32000 Series
Long Drop Powershift Transmission

CLARK



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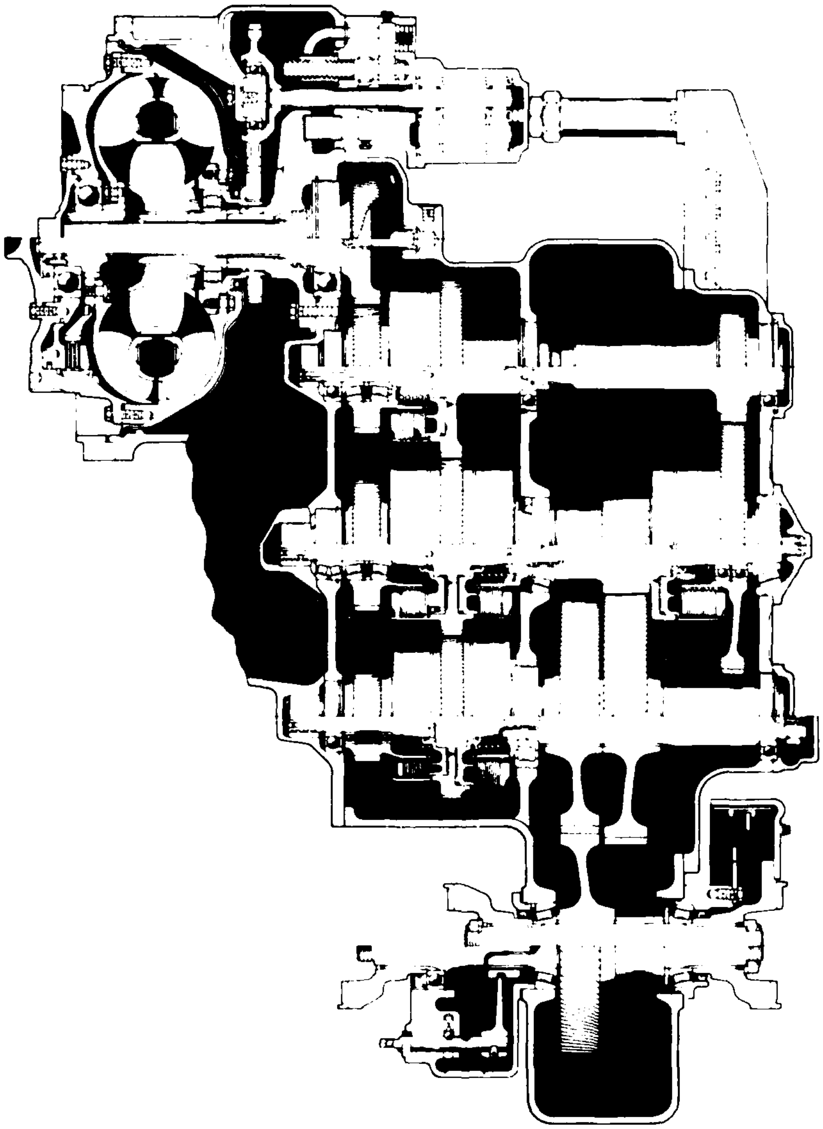
DESIGNED FOR USE WITH CLARK TORQUE CONVERTERS.

SPECIFICATIONS AND/OR DESIGNS ARE SUBJECT TO CHANGE WITHOUT NOTICE OR OBLIGATION

CLARK COMPONENTS COMPANY

BUCHANAN, MICHIGAN U.S.A. 49107

34000 Series



Specifications

Number of Speeds:

Full Powershift

3 Speed
4 Speed
6 Speed

Ratios

	3 Speed	4 Speed	6 Speed	
Model	34340	34440	34640	
	Fwd & Rev	Fwd & Rev	Fwd & Rev	
1st	5.85	5.85	7.15	7.5
2nd	2.44	2.44	5.22	2.98
3rd	.79	1.39	2.98	.96
4th		.79	2.17	
5th			.96	
6th			.70	

Wide range of ratios available for most industry requirements. Contact the Marketing Communications Department, 324 East Dewey Ave., Buchanan, MI, 49107, for more information.

Configurations:

Long Drop

Remote Mounted Transmission
Midship Mounted Converter/Transmission
Engine Mounted Converter/Transmission

Options:

Lock-up: Electric and Automatic
Clutch Modulation
Controls: Mechanical or Electric
Clutch Disconnect: Air or Hydraulic
Inching Valve: Mechanical or Hydraulic
Pump Disconnect
Axle Disconnect, Front or Rear
Mechanical Parking Brake
Emergency Steering Pump Drive
Tachometer Drive
Speedometer Drive
Interaxle Differential

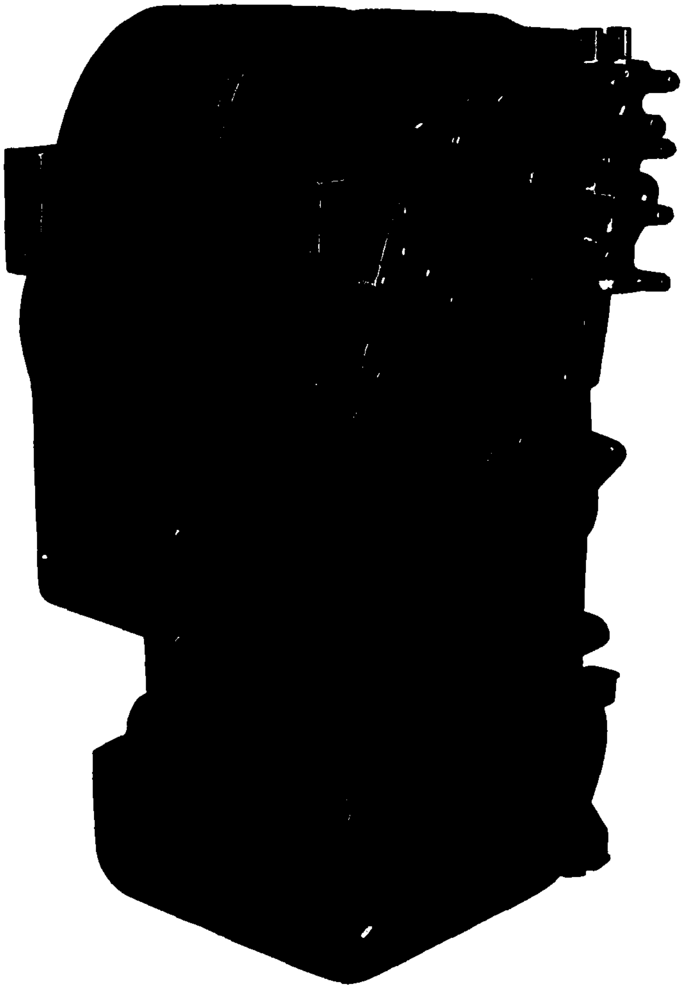
Converter:

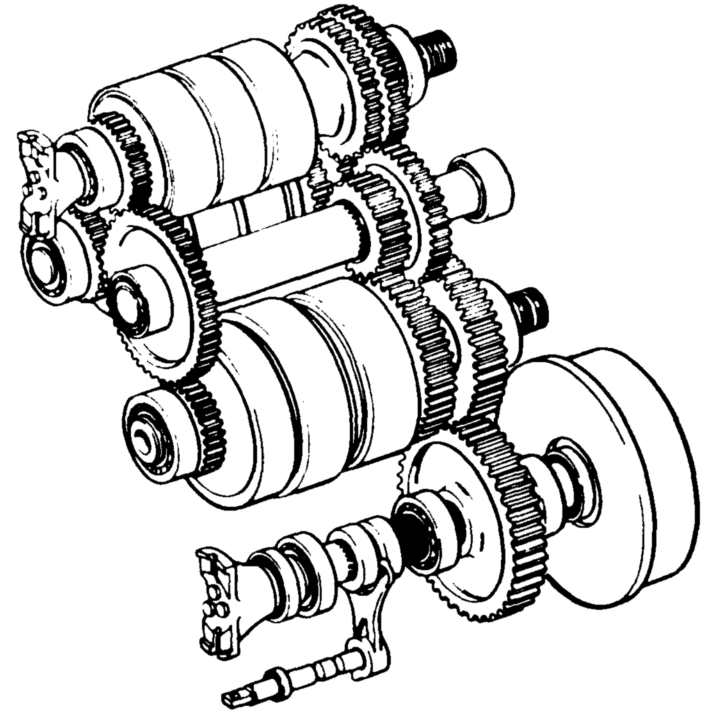
H & MHR 34000 Converter-Transmission Series

Converter Identification	14	14.1	14.3	14.4	14.5	14.7	15	15.5	16
Circuit Diameter	14″	14″	14″	14″	14″	14″	15″	15″	16″
Stall Torque Ratio	3.140	2.715	2.039	2.218	1.820	2.292	3.090	1.780	3.050

Twin Disc Power Shift Transmissions

TWIN DISC 1130 Series...150 to 325 h





APPLICATIONS

Crash trucks•Rubber tire tractors•Rail switchers and equipment•Logging yarders•Specialized mining equipment•Crane carriers•Off-highway haul trucks•Scrapers•Snow plows•Oil field equipment•Winches and hoists•Compactors•Log loaders•Special purpose equipment•Airport vehicles.

The 1130 Series provides power-shifting in all four forward and reverse speeds. Several ratio spreads are available. The 1130 Series is also available with five or six speeds forward, one reverse. The 1130 is rated between 150 and 325 hp* (gross). Maximum input speed is 2800 rpm*

*Depending on specific model transmission—contact Twin Disc for optional ratings

MOUNTING—Either remotely-mounted transmission and engine-mounted hydraulic torque converter, or integral transmission and torque converter mounted on the engine, depending on torque converter selection.

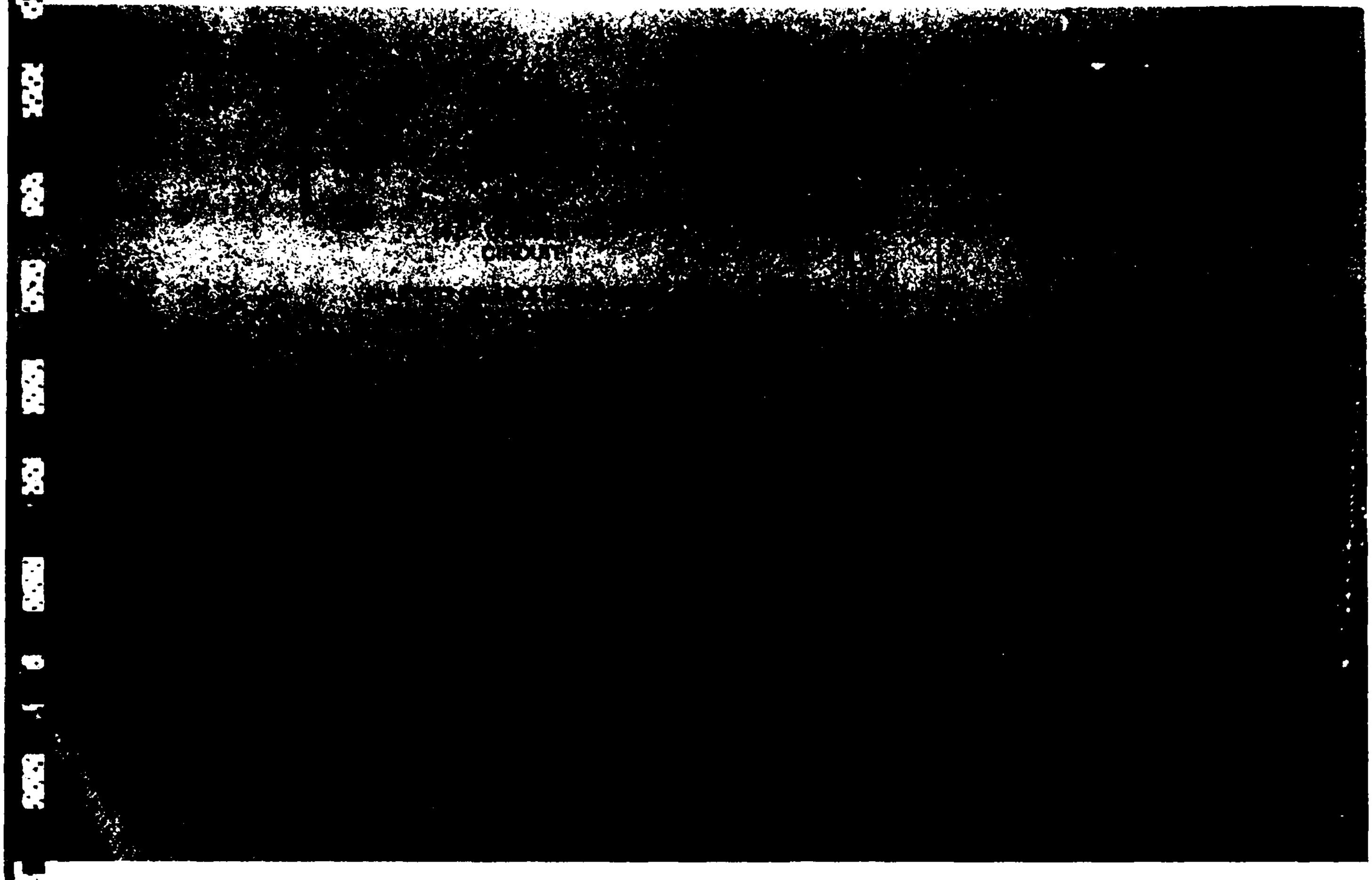
HYDRAULIC TORQUE CONVERTER—Single-stage 15", Type 6 circuit or 14.5 or 16", Type 8 circuit; wet flywheel.

Ratios

MODEL TD, TDC	FORWARD AND REVERSE				
	1st	2nd	3rd	4th	OVERALL
44-1131	3.90	2.46	1.19	.660	5.92
44-1132	4.68	2.59	1.19	.660	7.11
44-1133	5.96	3.03	1.51	.77	7.73
44-1141	4.95	2.74	1.51	.840	5.92
44-1142	5.04	2.79	1.28	.710	7.11

Additional Ratios Available

rsepower



Specifications

Maximum Input Speed—RPM	2800
Cooling Flow Available—GPM @ 2000 RPM*	17
Maximum Temperature of Converter Oil	250° F.
Cooling Required—% of Maximum Input Horsepower*	33-1/3%
Oil Type	SAE 10W Class CD or Automatic Transmission Fluid—Type C-3
Oil Capacity—Gallons (Approx.)	11
Converter Flywheel Housing—Wet Type	SAE No. 1
Weight—Converter (Approx.)	537 lbs.
Transmission (Approx.)	1250 lbs.
Transmission Output: Front and Rear	Standard
Speedometer Drive	Standard
Retarder (Except 15" converter)	Optional
Retarder Capacity—Lbs.-Ft. @ 2000 RPM	700
Parking Brake	Optional
Brake Controlled Declutch	Optional
Automatic Lock-Up (Except 15" converter)	Optional
Power Pump Drive	Optional
Electric Range Selector System	Optional
Output Disconnect	Optional

*—Contact Transmission Application Engineering, Rockford [illegible] retarder cooling requirement

ZF Power Shift Transmissions

ZF Powershift transmissions of the WG range

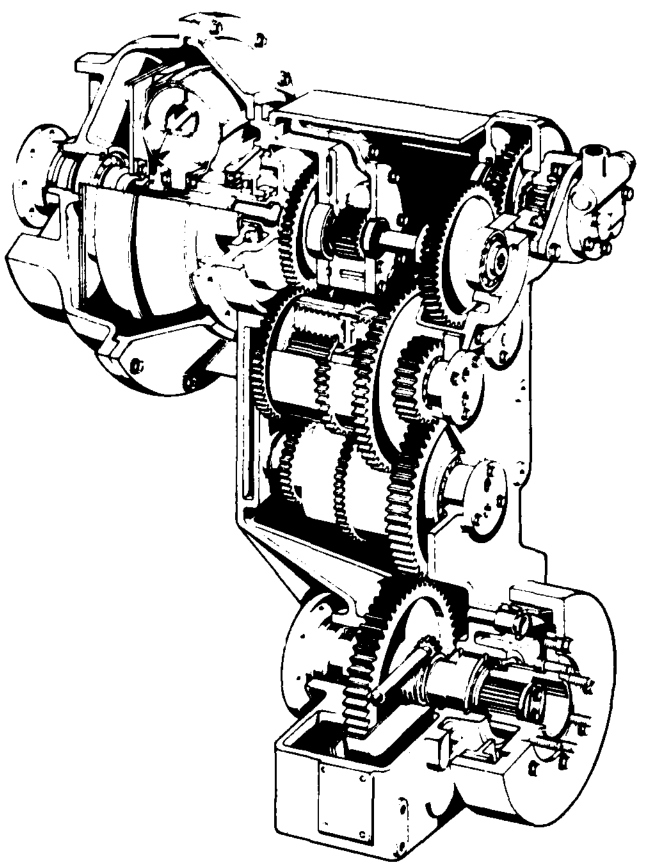
Zahnradfabrik Passau GmbH has a wide range of powershift transmissions available in the so-called WG range to cater for the sector of drive technology in the field of construction machines, construction site vehicles and industrial lift trucks as well as a versatile range of mobile working machines.

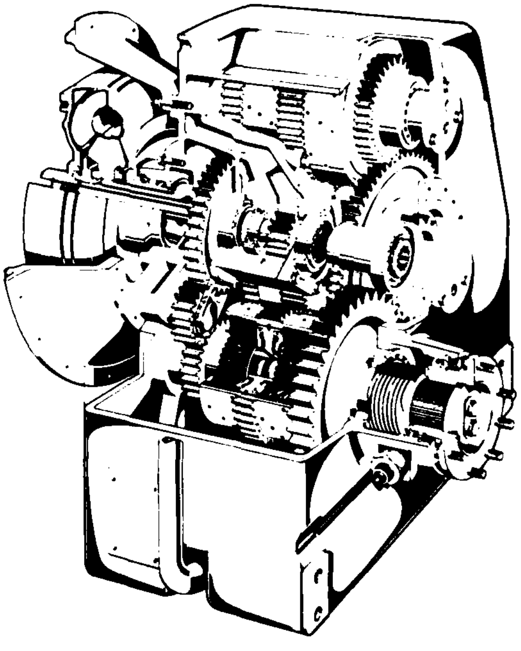
Design		Performance range
long centre distance Model	short centre distance Model	up to kW
WG 120	WG 121	105
WG 150	WG 151	135
WG 180	WG 181	170
WG 200	WG 201	190

These powershift transmissions consist of a hydrodynamic torque converter and a rear-mounted reversing transmission of countershaft design and hydraulically actuated disc clutches. The supply options have 3, 4, 5, or 6 forward and 3 reverse gears.

The dimensions of **the models WG 120 and WG 150 respectively the models WG 180 and WG 200** are identical. Thanks to the four-wheel drive and the large centre distance between input and output shaft these are particularly suitable for installation in bukket loaders, bulldozers, skit steer vehicles, graders, mobile trains, timber extraction vehicles, dumpers, roll-on-roll-off tractors, rail-mounted vehicles and so on.
For technical details and installation dimensions, see pages 5 - 9 inclusive.

The dimensions of **the models WG 121 and WG 151 respectively the models WG 181 and WG 201** are also identical. However, these transmissions only have one output which is located under the input shaft with only a short centre distance. As a result, they are particularly suited to installation in crawler-mounted graders, crawler-mounted loaders, fork lift trucks, rubber wheel compacters, industrial tractors and shunting engines.
For technical details and installation dimensions see pages 10 - 13 inclusive.





for the transmissions of the WG range

The powershift transmissions of the WG range can be adapted to suit an extremely wide range of installation and operating conditions due to its different versions and the range of additional equipment

Installation options

The transmissions can be supplied for any of the following:

- **Flange mounting (1)** with various SAE engine connections or with
- an **end cover (4)** for separate installation

In addition, it is also possible to install the torque converter

- as a **separate converter transmission (6)** (model code HN 500 – see page 14).

In this case, the reversing transmission is equipped with an **input flange (7)**. With this configuration, the transmissions with four-wheel drive (WG 120/150 and WG 180/200) can also be driven from the reverse side.

Torque converter design

The characteristics of the **torque converter (2)** are particularly beneficial in heavy duty applications. This is especially true of its ability to increase tractive force when it encounters increasing tractional resistance. The rating of a converter is determined on the basis of engine and vehicle data. Depending upon what is required, it can be equipped with

- a stator free wheel
- a free wheel brake or with
- an automatically operating **lock-up clutch (3)**.

This clutch locks up the torque converter and does so at the point where torque conversion is nil, i.e when there is no increase in tractive force

Reversing transmission design

The four-wheel drive models are available with a range of **centre distances (8)** between input and output shafts: 500 mm with WG 120/150 and an option of 400, 500 or 555 mm on the WG 180/200.
Moreover, these transmissions can be equipped with the following components:

- a **disconnect device (9)** for the front output, on the WG 180/200 models, this is also possible for the rear output.
- a **parking brake (10)** on rear output
- a **speedometer connection (11)**
- an integrated, lockable **inter-axle differential (12)** – only on WG 180/200 – with a torque ratio of 1:1 or 1:2
- a flange mounted **axle drive (13)**
- an additional **multi-disc clutch (14)** which is necessary for the 4,5 or 6 speed version

It is also possible to have the following:

- an option of 1 or 2 **engine driven P.T.O. units (16)** – disengageable or constantly running – for fitting a pump for the hydraulic system which operates the implements and for steering power.
- a P.T.O., dependent on the reversing transmission (instead of the 2 nd engine driven P.T.O.)
- an optional connection for installing an **emergency steering pump (15)** or, on rail-bound vehicles a secondary pump
- output flanges for various universal shafts

The models with short centre distance (WG 121/151 and WG 181/201) are also be supplied as follows:

- a 4, 5 or 6 speed version with additional **multi-disc clutch (14)** as well as
- an **engine driven P.T.O. (16)** with an extension of the input shaft – disengageable or constantly running – to allow a pump to be fitted to operate the hydraulic system for the implements.
- with a **speedometer connection (11)**
- with output flanges for a variety of universal shafts

Transmission control system

The options for **transmission control (17)** are a mechanical-hydraulic system or an electro-hydraulic system, although the 5 and 6 speed models can only be operated by an electro-hydraulic control system.

The mechanical control is actuated by 2 spools. One has the positions „forward-neutral-reverse", the other is there for shifting the gears in numerical sequence. As addtitional equipment, a so-called safety pack can be supplied. This contains a reversing lock for gears 3 and 4 as well as a position for total neutral (all clutches vented)

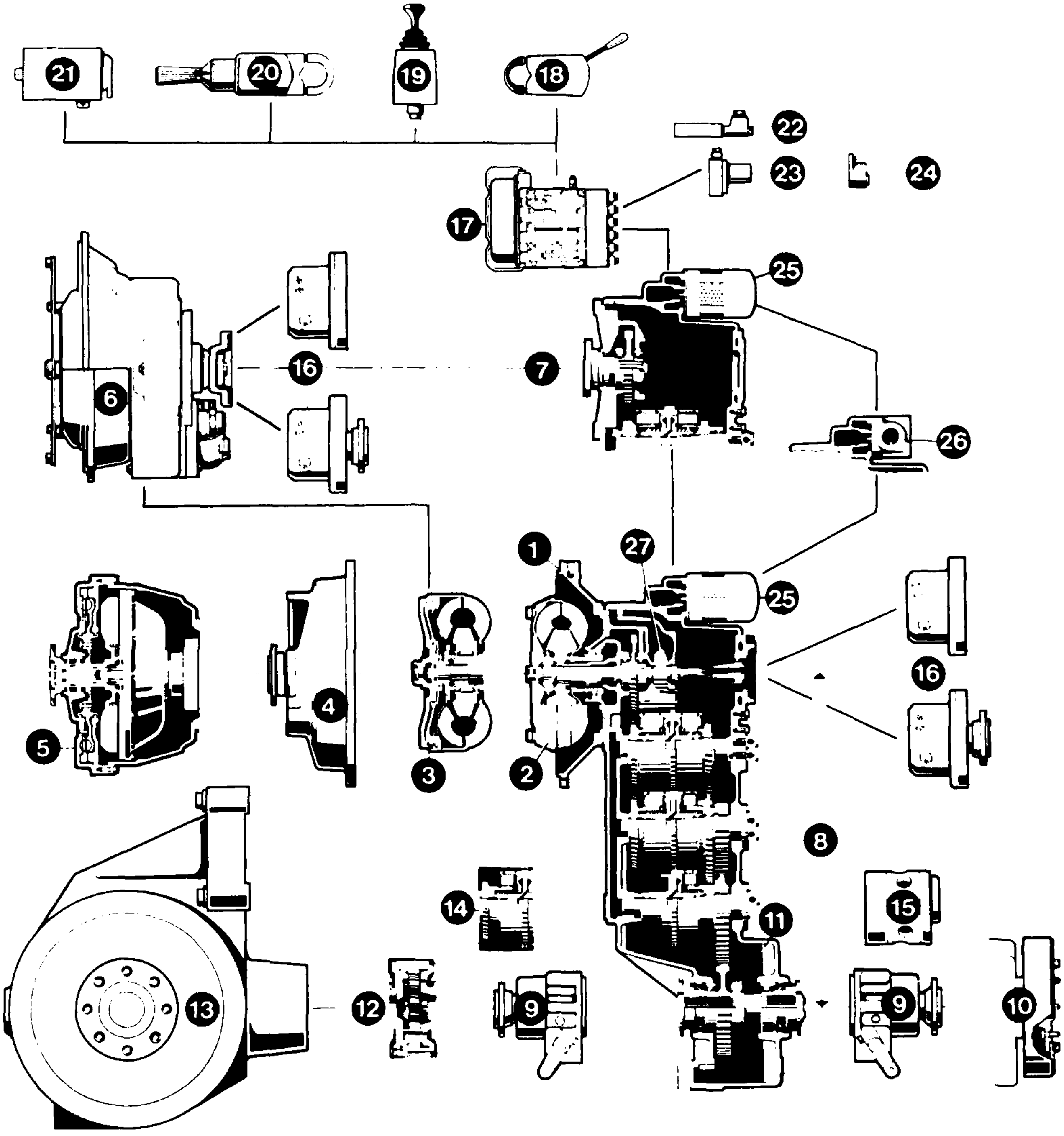
On the electrical control system , a range of selector switches are available options being

- **steering column control switch: SG 4/SG 6 (18), DW 1 (20)**
- **console switch: SG 4/SG 6 (19)**

Apart from the fact that it is much more convenient to install, the electrical control unit also has the following advantages

- installation of a **starter interlock** and a **reversing interlock**
- simplified form of automation with **ZF automatic control EST 2 (21)** – for this refer to separate technical data sheet F 43426/RT 3394.

With both control units (mechanical and electrical), it is possible to reverse while in motion in 1st and 2nd gear. In addition, by installing a **dual pressure control valve (23)** it is possible to optimize shift quality



1 Converter housing for direct installation
2 Torque converter
3 Lock-up clutch
4 Cover for separate installation
5 Retarder
6 HN 500 converter transmission
7 Input flange (for separate installation)
8 Centre distance input/output
10 Parking brake
11 Speedometer connection
12 Inter-axle differential
13 Axle drive, flange-mounted
14 Multi-disc clutch for 4, 5 and 6-speed version
15 Emergency steering pump
16 PTO unit, engine driven
17 Transmission control
18 Steering column switch SG 4/
19 Console switch SG 4/SG 6
20 Rotary reversing switch DW 1
21 Automatic control unit EST 2
22 Inching valve
23 Dual pressure control valve
24 Pressure cut-out
25 Micro-filter
26 Transmission connection for separate filter installation
27 Converter charge and shift

Retarder

Transmissions of the WG range can, if so desired, be equipped with a **retarder (5)**. However, this is only possible in the version for separate installation.

Converter unit

The **HN 500 (6)** converter transmission – technical details and installation dimensions given on page 14 – can only be flange mounted, although it can, be supplied with a range of SAE engine connections. The torque converter can optionally be equipped with a stator free wheel and also with an automatically engaging lock-up clutch. The converter charge and shift pump, with the necessary pressure and suction line connections for the reversing transmission are integrated in the HN 500 unit.

In addition, there are 2 possible connections on the converter transmission for **engine driven P.T.O.s (16)** – disengageable or constantly running – (for the installation of a pump to operate implement hydraulics and boost steering power).

Pressure cut-out

On vehicles such as bucket loaders and crawler-mounted loaders, a **pressure cut-out (24)** must be fitted to enable full engine power to be supplied to the hydraulic system controlling implements. This device interrupts the oil pressure in the multi-disc clutches. In the case of mechanical transmission control, it is integrated in the shift block and can be actuated hydraulically or pneumatically by means of a second brake pedal (working brake).

On electric transmission control systems, pressure cut-out is actuated by a switch on the brake pedal. This interrupts the electrical supply to the solenoid valves. The switch may however not operate until a brake presssure of 2.5 bar has been reached.

Inching device

Vehicles such as fork-lift trucks require an inching device so that they can advance at the lowest possible speed (crawling) without any alteration to engine speed. Transmissions affected by this are therefore equipped with a **crawler valve (22).** Operation is either by means of the brake pedal or a separate inching pedal.

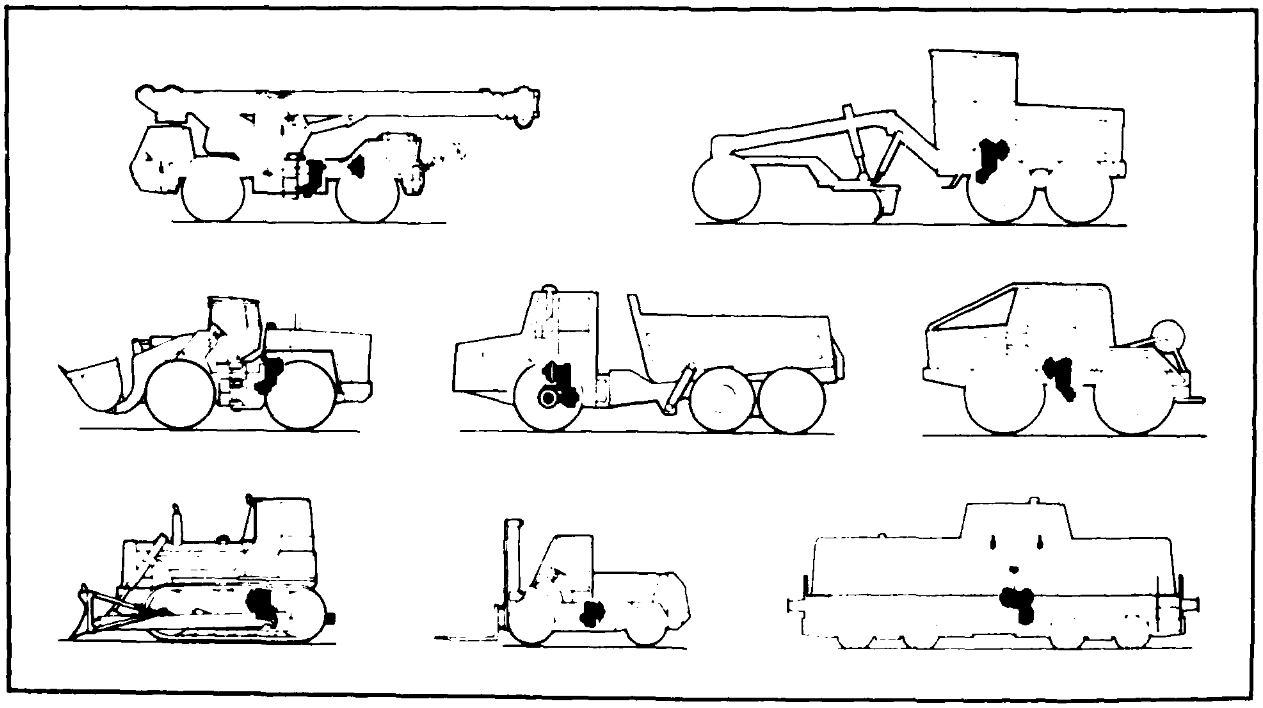
Oil supply

The **pump (27)** needed for the oil supply of the torque converter and the control system is installed in the transmission. The oil is cleaned in the main oil flow. The **micro-filter (25)** required for this can either be fitted to the transmission or installed separately in the vehicle – the **transmission connection (26)** is there for separate installation of filter.

Heat exchanger

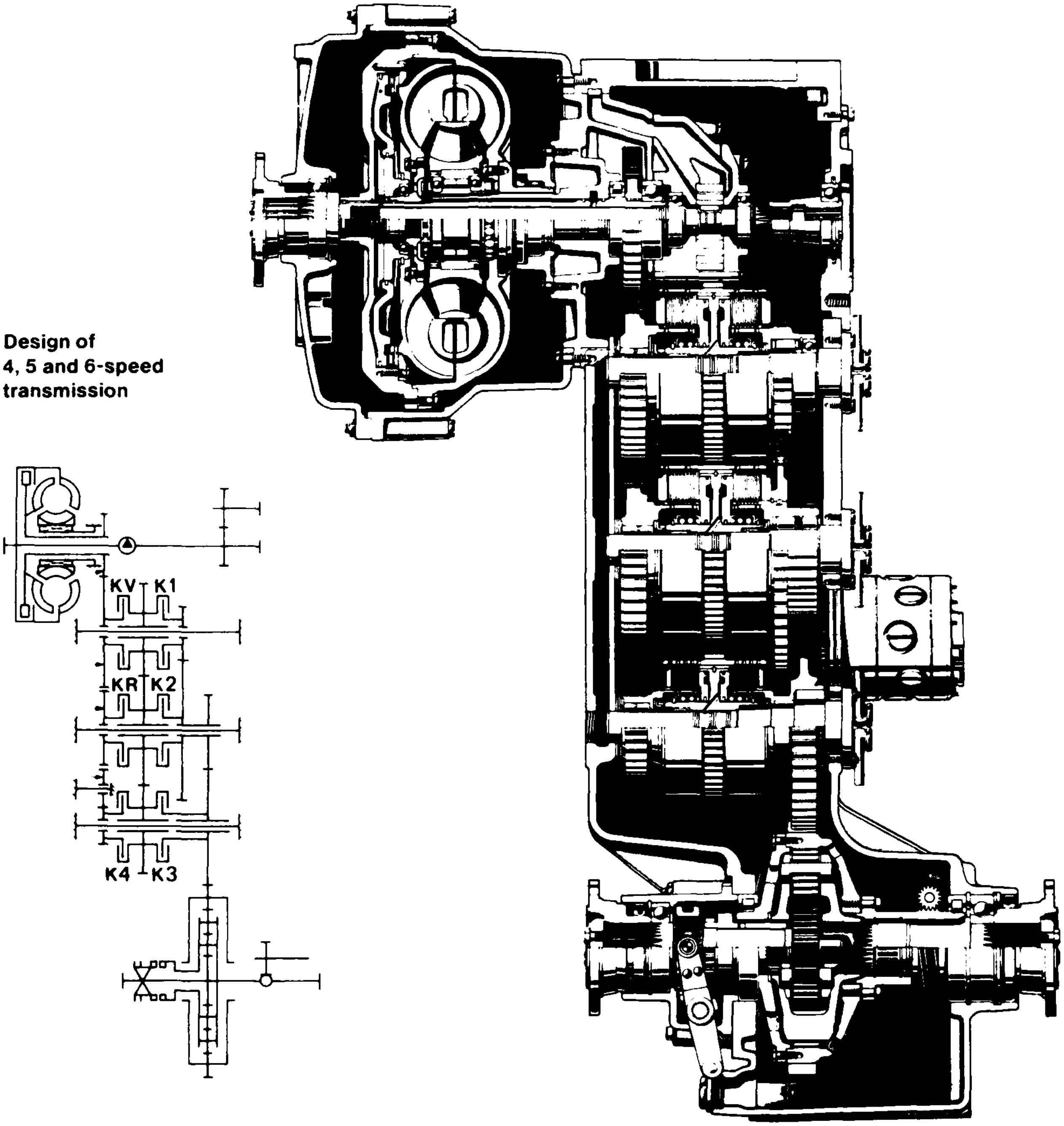
A heat exchanger is provided for cooling torque converter and lubrication oil (see installation instructions page 15, item 12).

Applications



Four-wheel drive versions

Models WG 120, WG 150 and WG 180, WG 200

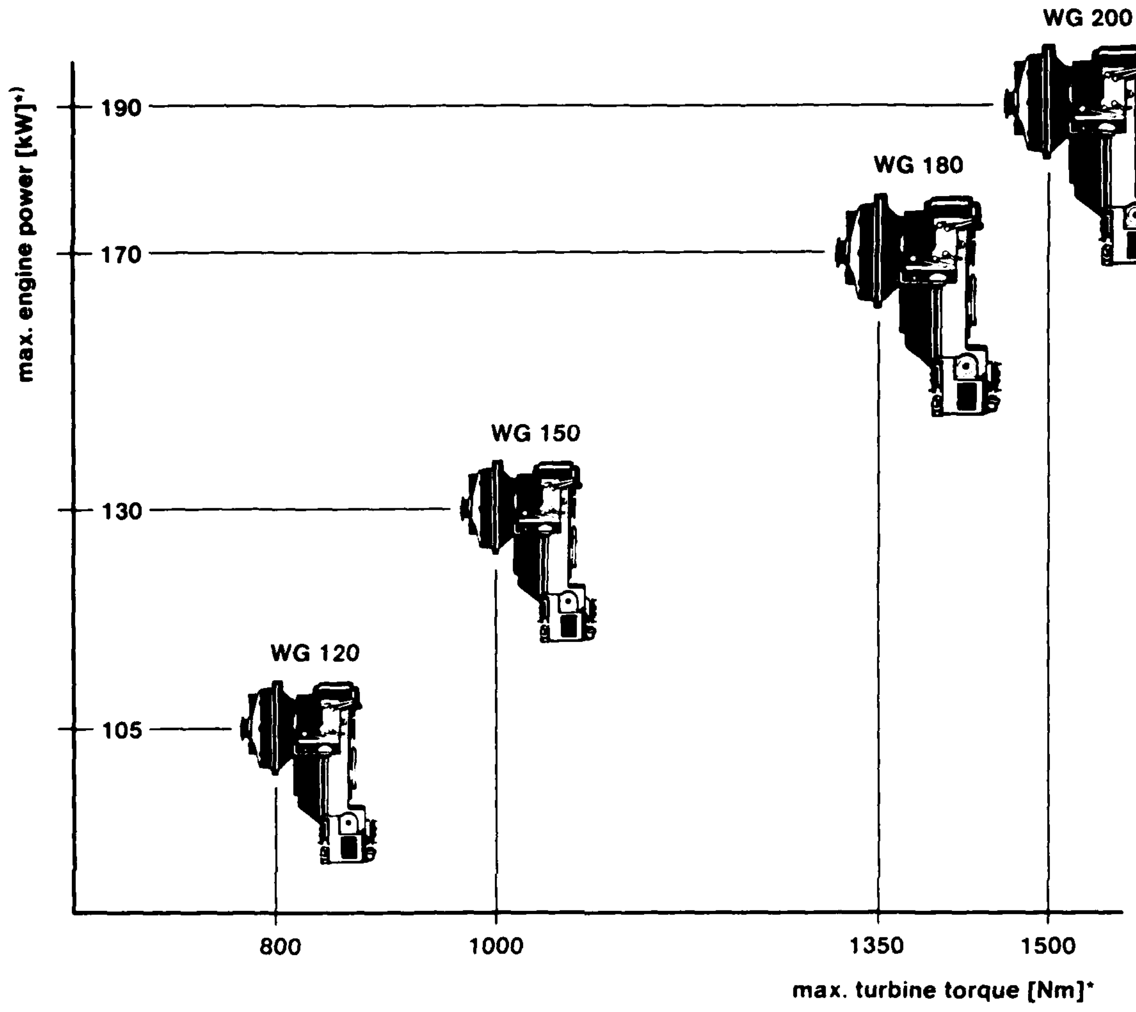


Design of
4, 5 and 6-speed
transmission

Clutches operated on 5 and 6-speed transmission (see diagram)

	1st gear	2nd gear	3rd gear	4th gear	5th gear	6th gear
Forward	KV + K1	K4 + K1	KV + K2	K4 + K2	KV + K3	K4 + K3
Reverse	KR + K1	KR + K2	KR + K3	–	–	–

Technical data (WG 120/150 and WG 180/200)



			WG 120 and WG 150	WG 180 and WG 200
Engine speed *)			max 2 800/min	
Stall torque ratio			dependent on converter version 1 5 to 3 2	
P.T.O. units	**Engine driven**	T_{out} **total**	max 500 Nm	max 700 Nm
		n_{out}	1 0 x n_{engine}	1 0 x n_{engine}
	Reversing transmission dependent	T_{out}	max 710 Nm	max 1270 Nm
		n_{out}	1 04 x n_{turb}	1 053 x n_{turb}
Speedo drive			n_{out}/n_{speedo} = 2 67	n_{out}/n_{speedo} = 2 67
Mass **) (without oil)		**3 WG . . .**	approx 290 kg	approx 390 kg
		4 WG . . .	approx 350 kg	approx 450 kg
		5/6 WG . . .	approx 350 kg	approx 450 kg

*) dependent on type of vehicle and application **) dependent on transmission version

Ratios (WG 120/150 and WG 180/200)

		Ratios								
		Forward						Reverse		
Model	Version	1st.	2nd	3rd	4th	5th	6th	1st	2nd	3rd
WG 120 and WG 150	3 WG ...[1] 4 WG ...	3.91	2.304	0.964	0.617			3.91	2.304	0.964
		4.425	2.25	1.0	0.64			4.425	2.25	1.0
		4.531	2.304	0.964	0.617			4.531	2.304	0.964
		4.531	2.9	1.475	0.617			4.531	2.9	1.475
		5.9	2.304	0.964	0.617			5.9	2.304	0.964
		5.9	3.775	1.475	0.617			5.9	3.775	1.475
	5 WG ...[2] 6 WG ...[2]	4.531	2.9	2.304	1.475	0.964	0.617	4.531	2.304	0.964
		5.292	3.387	2.304	1.475	0.964	0.617	5.292	2.304	0.964
		5.9	3.775	2.304	1.475	0.964	0.617	5.9	2.304	0.964
WG 180 and WG 200	3 WG ...[1] 4 WG ...	3.918	2.366	1.125	0.611			3.918	2.366	1.125
		4.166	2.594	1.178	0.672			4.166	2.509	1.178
		4.271	2.531	1.237	0.706			4.271	2.531	1.237
		4.975	2.531	1.237	0.706			4.975	2.531	1.237
		5.099	2.594	1.178	0.672			5.099	2.594	1.178
		5.373	2.594	1.178	0.672			5.373	2.594	1.178
		5.986	2.594	1.178	0.672			5.986	2.594	1.178
	5 WG ...[2] 6 WG ...[2]	5.986	3.42	2.594	1.48	1.178	0.672	5.986	2.594	1.178
		5.986	3.904	2.594	1.692	1.178	0.768	5.986	2.595	1.178
		5.987	3.416	2.74	1.563	1.068	0.609	5.987	2.74	1.068

[1] The same ratios apply for the 3-speed versions (without 4th gear).

[2] The 5- and 6-speed versions are only supplied with elektro-hydraulic gearshift. The same ratios apply for the 5-speed versions (without 6th gear).

Installation dimensions (WG 120/150 and WG 180/200)

Key to drawings

1	Torque converter
2	Micro-filter in main oil flow
4	Mounting pads
5	Front output; disconnect or with differential to order (flange type optional)
6	Speedo connection conforming to E2 DIN 75532 (position optional on WG 180/200)
8	Oil filler hole with dipstick **
9	Possible connection point for emergency steering pump
12	Engine driven P.T.O.
13	Option of 2nd engine driven P.T.O. or reversing transmission dependent P.T.O.
14	Rear output optionally fitted with parking brake (flange type optional)
15	Connection to heat exchanger
16	Connection from heat exchanger
20	Oil drain hole **
B1/2	Pressure cut-out valve, optional for pneumatic or hydraulic actuation

** The connections for the oil filler hole with dipstick and the oil drain hole may be exchanged

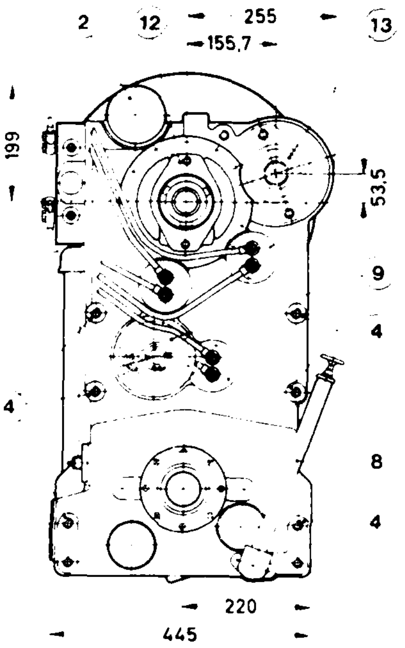
Versions

A 2	Electro-hydraulic control
A 4	Mechanical-hydraulic control for 3 and 4-speed versions
F	Converter bell housing with end cover and input flange for separate installation
G	SAE engine connection for direct installation
P	Rear output with parking brake

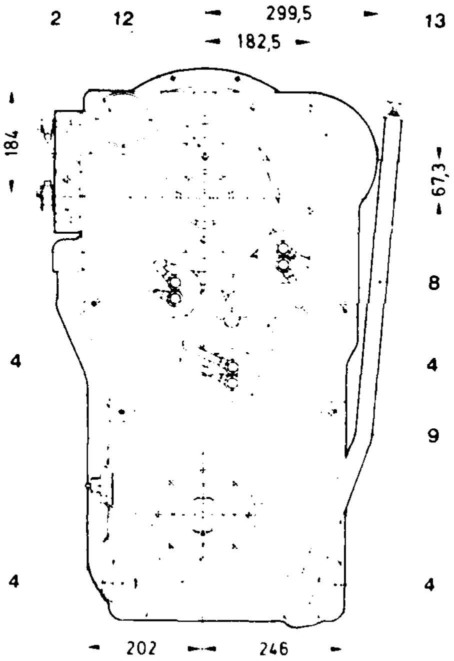
Dimensions given in ( ) apply to models WG 180/200

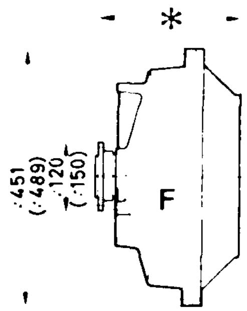
F*		WG 120/150	WG 180/200
Version	without lock-up clutch (WK)	251	278
	with lock-up clutch	352.5	360
	with lock-up clutch and retarder	370	377

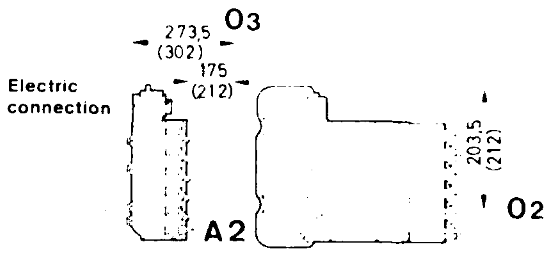
O3



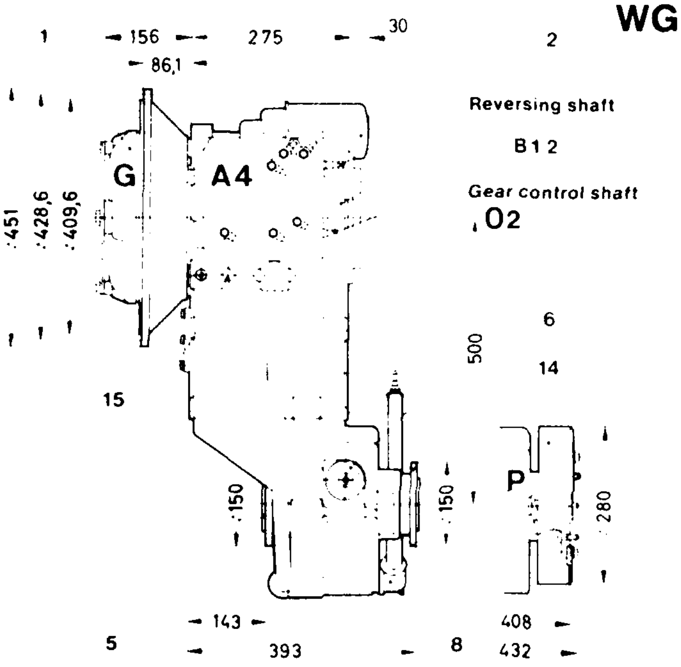
O3

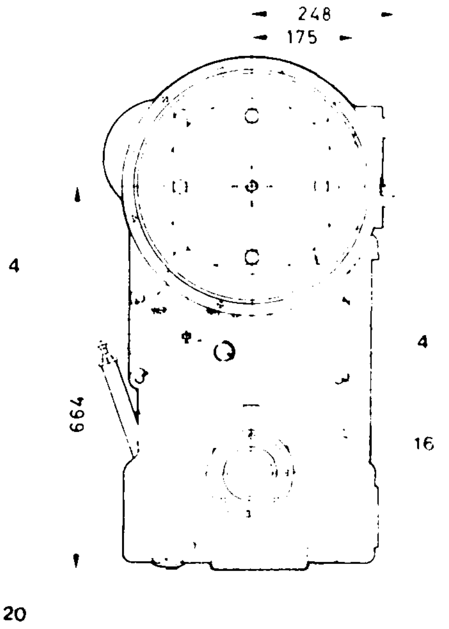



*
451
(489)
120
(150)
F

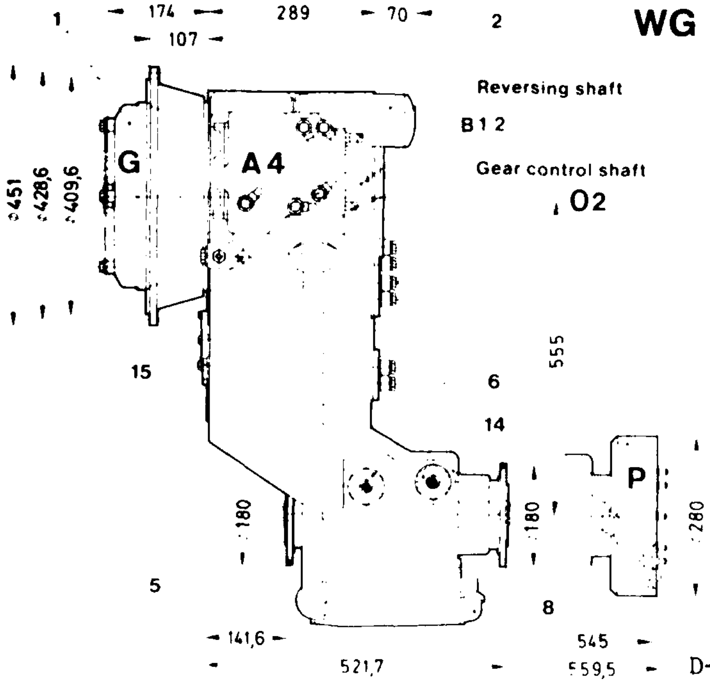

O3
273,5
(302)
175
(212)
Electric connection
203,5
(212)
O2
A2

WG 120/150

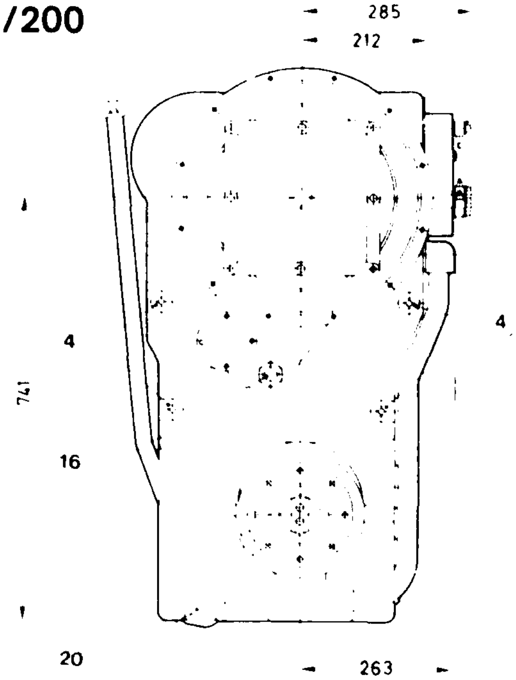

1
156
275
30
86,1
2
Reversing shaft
B12
Gear control shaft
O2
G
A4
451
428,6
409,6
500
6
14
15
150
150
P
280
143
408
5
393
8
432


248
175
4
664
4
16
20

WG 180/200

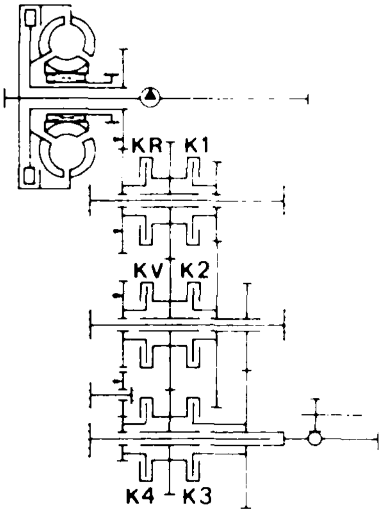

1
174
289
70
2
107
Reversing shaft
B12
Gear control shaft
O2
G
A4
451
428,6
409,6
555
15
6
14
P
180
180
280
5
8
141,6
545
521,7
559,5

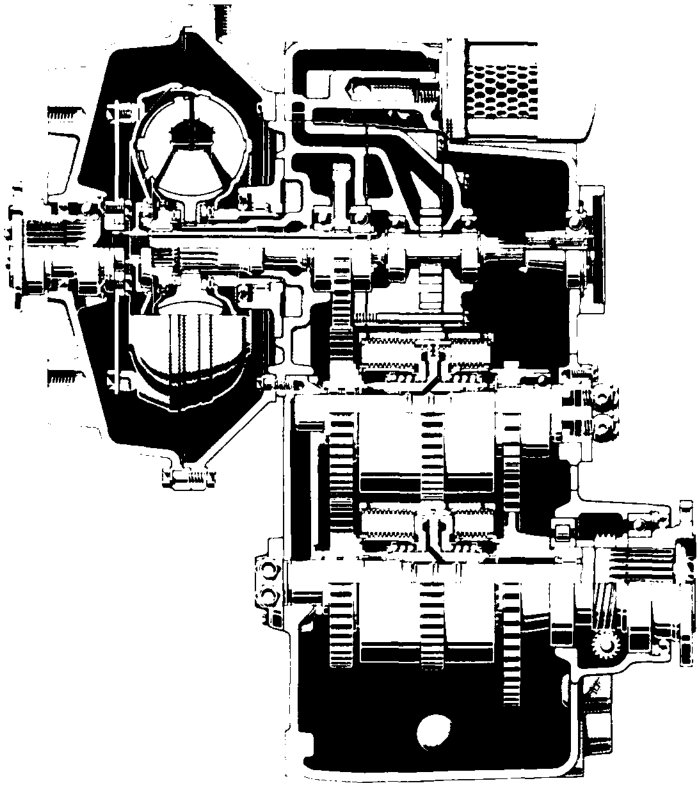
D-44


285
212
4
741
4
16
20
263

Models WG 121, WG 151 and WG 181, WG 201

Design of
4,5 and 6-speed
transmission





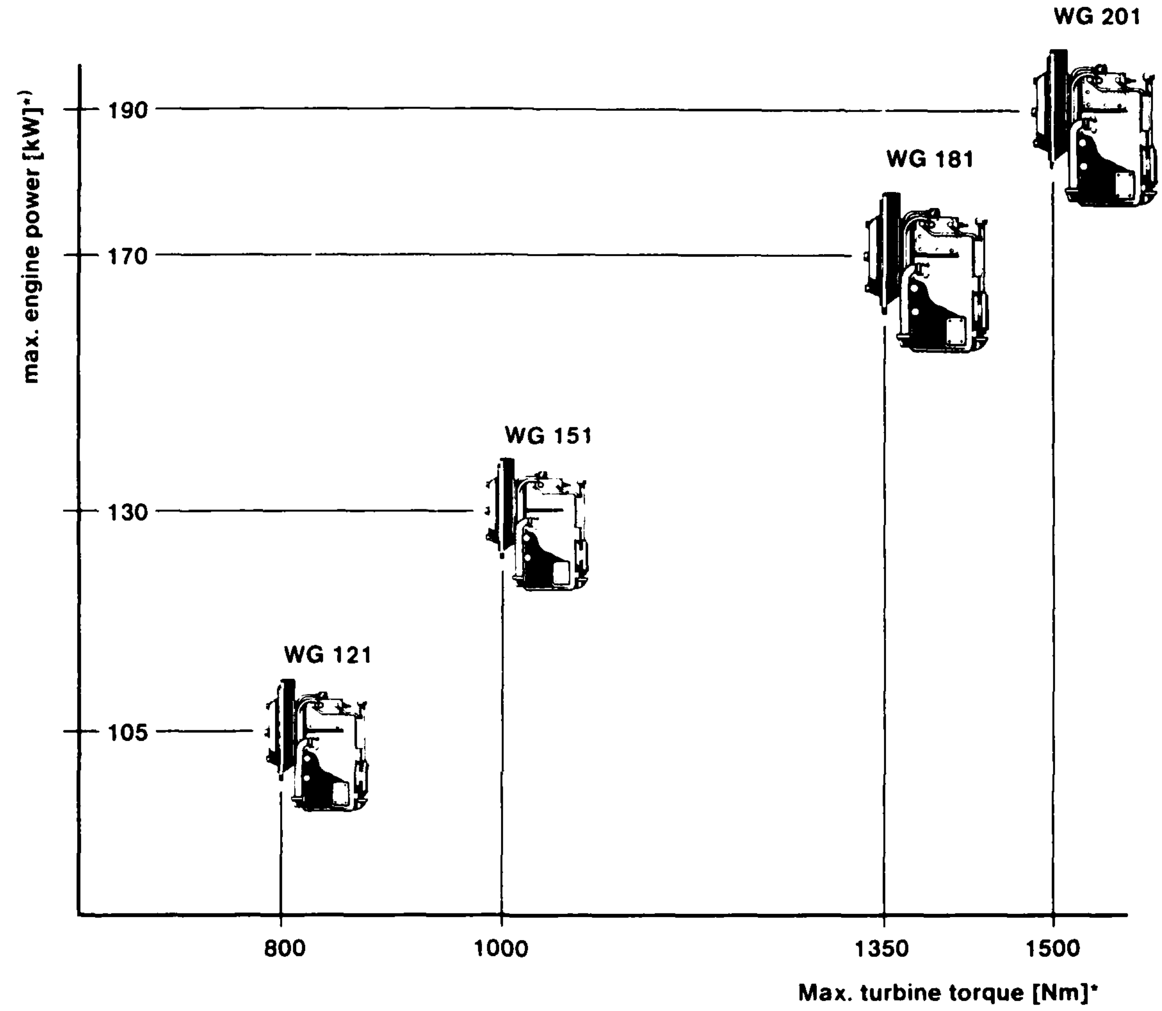
Clutches operated on 5 and 6-speed transmission (see diagram)						
	1st gear	**2nd gear**	**3rd gear**	**4th gear**	**5th gear**	**6th gear**
Forward	KV + K1	K4 + K1	KV + K2	K4 + K2	KV + K3	K4 + K3
Reverse	KR + K1	KR + K2	KR + K3	–	–	–

Technical data

		Ratios								
		Forward						**Reverse**		
Model	**Version**	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**1st**	**2nd**	**3rd**
WG 121 and WG 151	**3 WG ...**[1]	4.70	2.39	1.0	0.64			4.70	2.39	1.0
	4 WG ...	6.12	2.39	1.0	0.64			6.12	2.39	1.0
	5 WG ...[2]	4.7	3.0	2.39	1.53	1.0	0.64	4.70	2.39	1.0
	6 WG ...[2]	6.12	3.92	2.39	1.53	1.0	0.64	6.12	2.39	1.0
WG 181 and WG 201	**3 WG ...**[1]	5.736	2.485	0.968	0.632			5.736	2.485	0.968
	4 WG ...									
	5 WG ...[2]	5.736	3.74	2.485	1.62	0.968	0.632	5.736	2.845	0.968
	6 WG ...[2]									

[1] The same ratios apply for the 3-speed versions (without 4th gear)

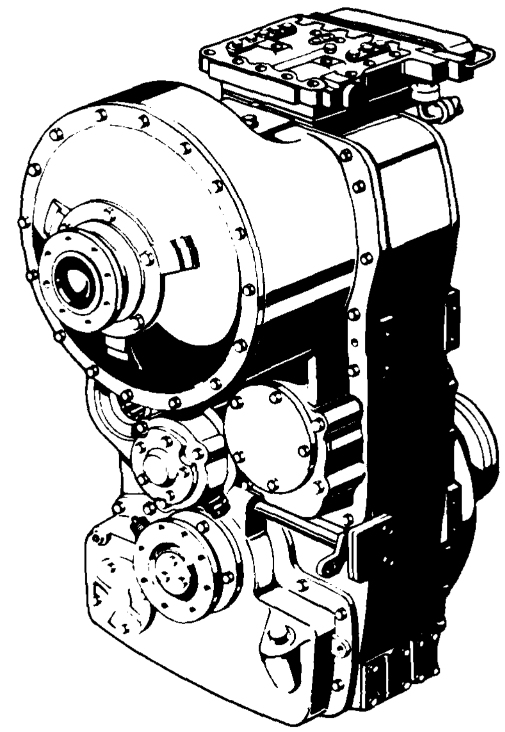
[2] The 5 and 6-speed versions are only supplied with electro-hydraulic gearshift
The same ratios apply for the 5-speed versions (without 6th gear)



	WG 121 and WG 151	WG 181 and WG 201
Engine speed *)	max. 2 800/min	max. 2 800/min
Stall torque ratio	dependent on converter version 1.5 to 3.2	
P.T.O. T_{out}	max. 500 Nm	max. 700 Nm
engine dependent n_{out}	1.0 x n_{engine}	1.0 x n_{engine}
Speedo drive	$n_{out}/n_{speedo} = 1.545$	$n_{out}/n_{speedo} = 1.545$
Mass **) (without oil) **3 WG ...**	approx. 220 kg	approx. 300 kg
4 WG ...	approx. 250 kg	approx. 370 kg
5/6 WG ...	approx. 250 kg	approx. 370 kg

*) dependent on vehicle type and application **) dependent on transmission version

ZF Hydromedia reversing gearbox 4 WG 65 II



The ZF Hydromedia reversing gearbox 4 WG 65 II consists of a hydrodynamic torque converter (Föttinger converter), and a rear mounted 4-speed reversing and transfer gearbox of the countershaft and planetary type. It can be used in various applications e.g. in heavy shovel loaders, graders or similar vehicles and is installed separately from the engine (input via a propshaft).

The favourable characteristics of the converter (e.g. increase in tractive power with increasing rolling resistance) are used to full advantage in all speed ranges and in both directions of rotation. Up and down changes of the four speeds can be carried out under load in both directions of travel.

The converter can be supplied with or without brake free wheel depending on the installation of the gearbox. The brake free wheel increases the braking effect of the engine during downhill travel.

The power for forward and reverse travel is transmitted via a spur gear countershaft assembly by means of hydraulically actuated multiple disc clutches and a planetary gear with hydraulically actuated multiple disc brake. Selection of gearbox is made electro-hydraulically. The gear changing operation is carried out via a universally adjustable standard selector switch. This can be mounted in various positions on the steering column, on the dashboard or on a console.

The model 4 WG 65 II is constructed for all-wheel drive and one of the outputs can be disconnected. Disconnection can be carried out whilst the vehicle is moving, but the connection of the drive should only take place with the vehicle stationary. If required, the gearbox can be supplied with a parking brake.

F 41519/R 1956-1275 E

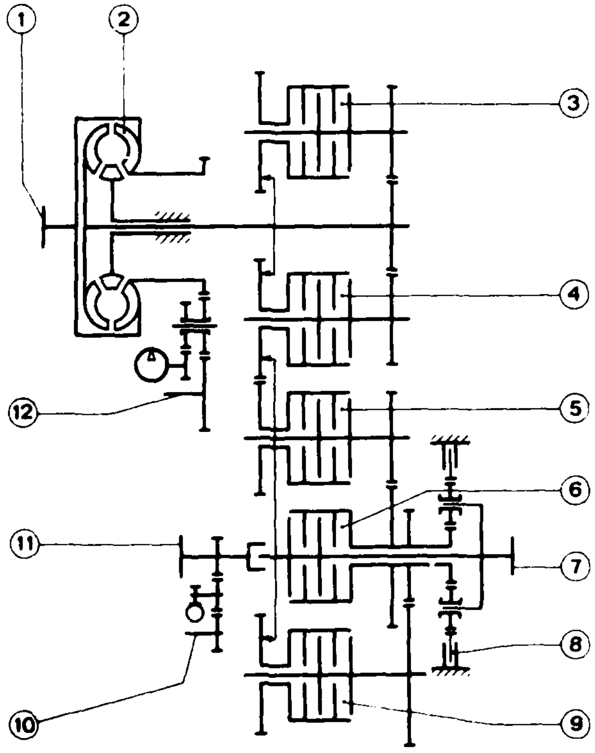
The converter filling- and shift pump is accommodated in the converter housing. The pump supplies the foam-free oil for the converter oil circuit. Cleaning of the oil takes place in the main oil flow. The filter used for this purpose is not attached to the gearbox in order that it may be positioned in the most convenient and accessible place in the vehicle. The control parts and valves are arranged on the gearbox such that they too are easily accessible from the outside. To cool the converter and lubricating oil circuit, an oil cooler with a capacity of approximately $1.4 \cdot 10^6$ J/kWh (250 kcal/HPh) is necessary. However, this value is only determining factor.

The gearbox is equipped for driving the steering pump and the pumps for hydraulic operating equipment with two engine controlled power take offs. However, an emergency steering pump can be fitted which is dependent on the driving revs.

Power can be cut off (e.g. on shovel loaders) by breaking the voltage for the magnets. A switch for this is fitted on the brake pedal, but this may be only operated at a braking pressure of 2.5 bar (atu).

Technical data

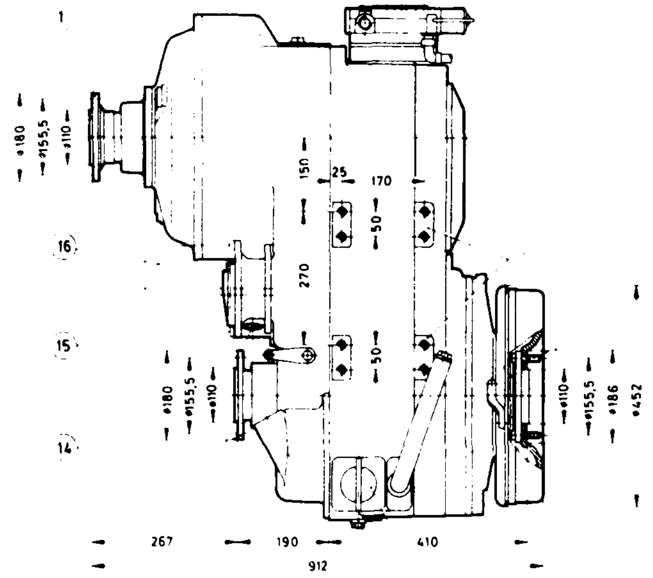
Input power	max kW (HP)	260 (350)		Mass (Weight) approx. 850 kg (1,875 lbs.)
Input speed	max r. p. m.	2500		Oil capacity approx. 40 dm^3
Input torque	max Nm (ft. lbs.)	1 000 (725)		
Ratios (mechanical) forward and reverse	1. gear	6.3	6.43	The max. torque increase of converter at stall point is 2.0 to 3.5 depending on type
	2. gear	2.63	3.36	
	3. gear	1.73	1.77	
	4. gear	0.72	0.924	
	engine dependent power take offs	1.05		



Schematic drawing of the gearbox

1. Input
2. Torque converter
3. Clutch "reverse"
4. Clutch "forward"
5. Clutch 1. and 3. gear
6. Clutch 3. and 4. gear
7. Output
8. Brake 1. and 2. gear
9. Clutch 2. and 4. gear
10. Connection for oil pump, depending on speed of output (e.g. for emergency steering pump)
11. Engageable and disengageable output
12. Connection for engine controlled power take off (i = 1.05)

Type 4 WG 65 II
(Basic version)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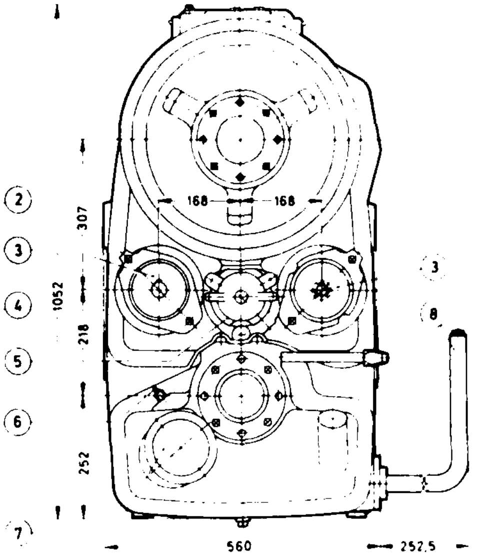
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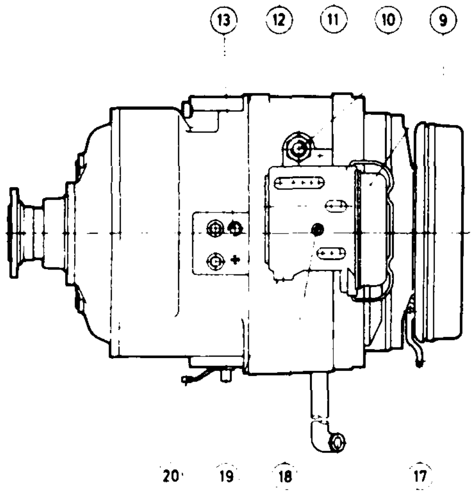
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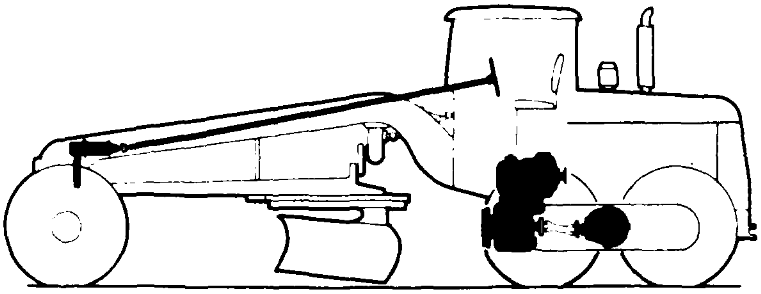
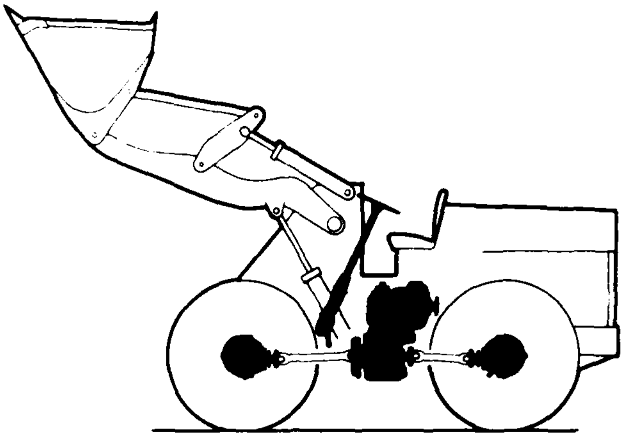
Key to drawings

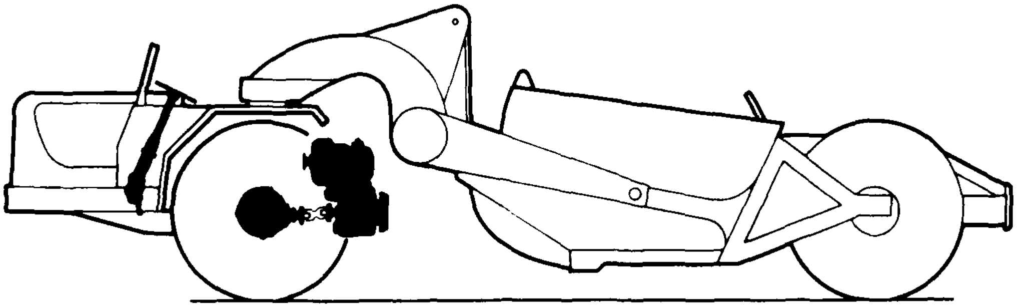
1. Input, 8 holes ø 14.1 mm
2. Mounting surfaces, thread M 16, depth of thread 30 mm
3. Connection for engine controlled power take offs (i = 1.05) e.g. for hydraulic pumps
4. Output, 8 bolts M 14
5. Converter filling- and shift pump
6. Speedometer connection
7. Connection for oil pump, output controlled (e.g. for emergency steering pump)
8. Oil inlet with measuring stick
9. Electro-hydraulic control
10. Connection from heat exchanger
11. Magnetic filter
12. Oil outlet
13. Connection to heat exchanger
14. Engageable and disengageable output
15. Connection to filter
16. Hydraulic pump (not supplied by ZF)
17. Lever for optional mounted parking brake
18. Connection for control pressure manometer
19. Connection from filter
20. Gear shift lever for all-wheel drive

Installation examples for the type 4 WG 65 II





The illustrations shows installation possibilities from the ZF range for fitting in a grader, shovel loader and scraper.



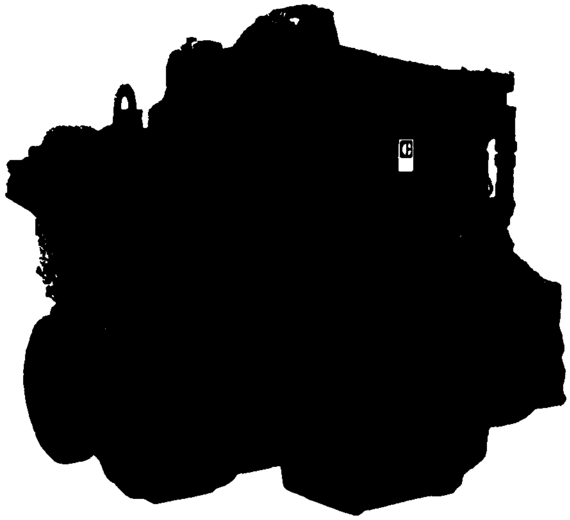
Subject to technical modifications.
For installation investigations please request respective installation drawings.
Dimensions are given in millimetres.

Caterpillar Engines

CAT
310 hp
2100 rpm

Diesel Truck Engine

FEATURES



FUEL ECONOMY

Variable-Timed Fuel Injection...Broad rpm Turbocharger Match...High Lift Cam Shaft...Full-Range Governor for Precise Speed Control...**Result: High mpg**

RELIABILITY AND DEPENDABILITY

Maintenance-Free Fuel System...Gear-Driven Water Pump...High Strength Bearings...**Result: Reduces Costly Road Failures and Shop Time**

EFFICIENCY MATCHED

Effective Operating Range...High Torque Rise...Big Displacement...Variable-Timed Fuel Injection... **Result: Less Shifting...Less Driver Fatigue**

LOW MAINTENANCE AND REPAIR COSTS

Exchange Components...Competitive Parts Prices ...Reusable Parts at Overhaul...Maintenance-Free Fuel System...**Result: Low Operating Costs**

PARTS AVAILABILITY

Computerized Parts System...High Parts Inventory ...Parts Distribution Centers...**Result: Reduces Costly Downtime**

DURABILITY

Hardened Liners...Total Hardened Crankshaft... Quality Standards...**Result: Less Downtime... Increased Revenue**

LOW OIL CONSUMPTION

Reduces Make-Up Oil Costs...Excellent Oil Control ...Less Maintenance Time...**Result: Reduces Oil and Maintenance Costs**

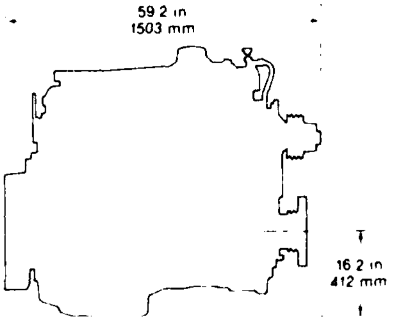
SPECIFICATIONS

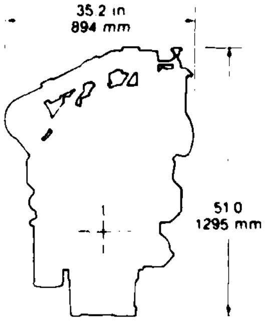
6 CYLINDER, 4-STROKE-CYCLE DIESEL

Bore	5.4 in (137 mm)	
Stroke	6.5 in (165 mm)	
Displacement	893 cu in (14.6 L)	
Aspiration	Turbocharged-Aftercooled	
Compression Ratio	14.5 to 1	
Rotation (from flywheel end)	Counterclockwise	
AMA Rating for U.S.A. Tax Purposes	70.0 hp	
Capacity for Liquids	U.S. Gal	Liter
Cooling System*	6.0	22.7
Lube Oil System (refill)	9.0	34.1
Weight, Net Dry (approximate)	2,870 lb (1302 kg)	

*Engine only. Capacity will vary with radiator size and use of cab heater.

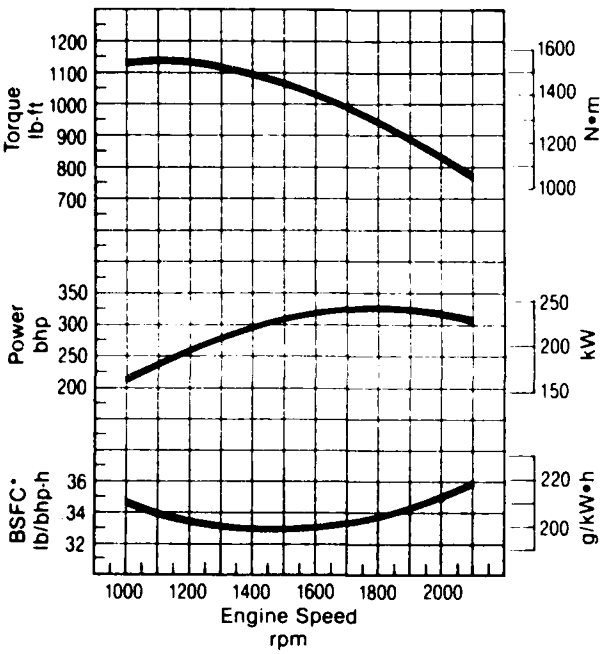
DIMENSIONS





3406B—310 hp DIESEL TRUCK ENGINE

PERFORMANCE CURVES



PERFORMANCE DATA

Rated hp (kW)	310 (231)
Full Load rpm	2100
Low Idle rpm	700
Operating Range (rpm)	1000
Altitude Capability—ft (m)	7,500 (2286)
Peak Torque—lb-ft (N•m)	1140 (1546)
Peak Torque rpm	1100
Torque Rise	47%
Weight per hp—lb (kg)	9.3 (4.2)

BSFC

The ratio of fuel burned to hp produced is defined as Brake Specific Fuel Consumption (BSFC). The BSFC curve shown above is at full load. While it is a standard industry practice to display rated (full load) BSFC curves, truck engines generally operate a very small portion of the time at full load. Instead, they operate on various part load BSFC curves which are too numerous to publish. Therefore, predicting fuel consumption from rated (full load) BSFC curves can be misleading. Caterpillar Truck Engines are designed to provide good fuel consumption throughout the entire operating range under both full load and part load conditions. Contact your local Caterpillar representative for further information.

STANDARD EQUIPMENT

- Air Compressor, Gear-Driven, 12 cfm (0.34 m^3/min)
- Air-Fuel Ratio Control
- Automatic Variable Timing
- Coolant Conditioner, Dry-Charge
- Crankcase Breather
- Dipstick (R.H. Side)
- Fan Drive (Adjustable)
- Flywheel and SAE No. 1 Housing
- Fuel Filter (Spin-On)
- Fuel Priming Pump
- Fuel Transfer Pump
- Governor Control
- Hydra-Mechanical Governor, Full-Range
- Jacket Water Pump, Gear-Driven
- Lifting Eyes
- Lube Oil Cooler
- Lube Oil Filter (Spin-On)
- Lube Oil Pump
- Oil Pan (Front or Rear Sump)
- Single Tach Drive (SAE Standard)
- Solenoid Shutoff (12 Volt)
- Turbocharger (Mid-Mounted)

OPTIONAL EQUIPMENT

- Air Cleaner with Service Indicator
- Alternator, 12 Volt, 65 Ampere
- Auxiliary Pulleys and Drives
- BrakeSaver (Hydraulic Retarder)
- Exhaust Fittings and Couplings
- Fans and Fan Accessories
- Primary Fuel Filter
- Starter (12 or 24 Volt)
- Transmission Mountings

RATING CONDITIONS

Performance is based on SAE J1349 standard conditions of 29.61 in. Hg (100 kPa) and 77°F (25°C).

Fuel consumption is based on fuel oil having an HHV of 19,590 Btu/lb (45 570 kJ/kg) and weighing 7.076 lb/U.S. gal (848 g/liter).

The curves shown are for a standard engine without fan, but equipped with air compressor and fuel, lubricating oil, and jacket water pumps.

Additional ratings may be available for specific customer requirements. Consult your Caterpillar representative for details.

*The International System of Units (SI) is used in this publication.

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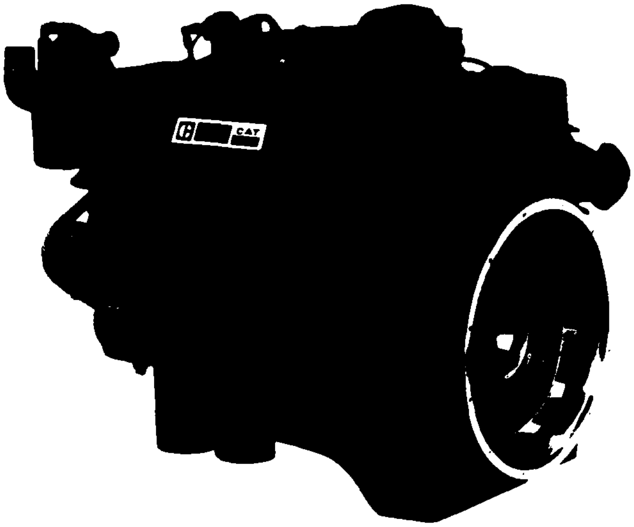
LEHT4082 (1-84)
Supersedes LEHT2251

Caterpillar, Cat and [illegible] are [illegible]

CAT
225 hp
2600 rpm

Diesel Truck Engine

FEATURES



FUEL ECONOMY

Full-Range Governor...Automatic Variable Timing Advance...**Result: Excellent Fuel Economy**

RELIABILITY AND DIESEL DURABILITY

Diesel Tough Components...Over a Quarter Million in Service Since 1967...**Result: Long Engine Life**

TOP PERFORMANCE

Immediate Response...High Torque Rise... Wide Operating Range...**Result: Peak Performance**

LOW MAINTENANCE COSTS

Simple Adjustments...Ease of Serviceability... Maintenance-Free Fuel System...**Result: Low Cost of Operation and Simplified Maintenance**

PRODUCT SUPPORT SERVICES

Over 2,000 Dealer Locations in North America... Computerized Parts System...Fast Parts Delivery ...**Result: Decreases Downtime and Increases Productivity**

REBUILDABILITY

In-Frame Overhaul, Out-of-Frame Overhaul, and Remanufactured Engines or Short Blocks Available for Fast Turnaround...Low Cost Exchange Components... Dry Repair Sleeves Available...**Result: Low Cost Per Mile of Operation**

BIG DISPLACEMENT

636 cu in (10.4 liter) Displacement...Excellent Acceleration and Response...**Result: Permits Use of Economical, Five-Speed Transmission**

METALLURGY AND DESIGN

Precise Casting of Cylinder Block and Heads in Caterpillar's Own Foundry...Two-Ring Pistons Reduce Friction Drag...Total Hardened Crankshaft...Crankshaft Regrindable...**Result: Structural Rigidity**

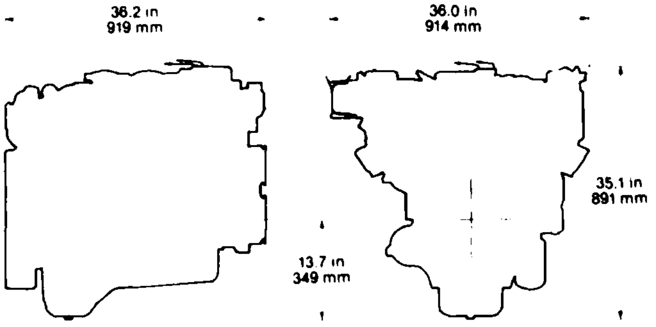
SPECIFICATIONS

8 CYLINDER, 4-STROKE-CYCLE DIESEL

Bore	4.5 in (114 mm)	
Stroke	5.0 in (127 mm)	
Displacement	636 cu in (10.4 L)	
Aspiration	Turbocharged	
Compression Ratio	16.5 to 1	
Rotation (from flywheel end)	Counterclockwise	
AMA Rating for U.S.A. Tax Purposes	64.8 hp	
Capacity for Liquids	U.S. Gal	Liter
Cooling System*	6.3	24.0
Lube Oil System (refill)	5.0	18.9
Weight, Net Dry (approximate)	1,450 lb	(658 kg)

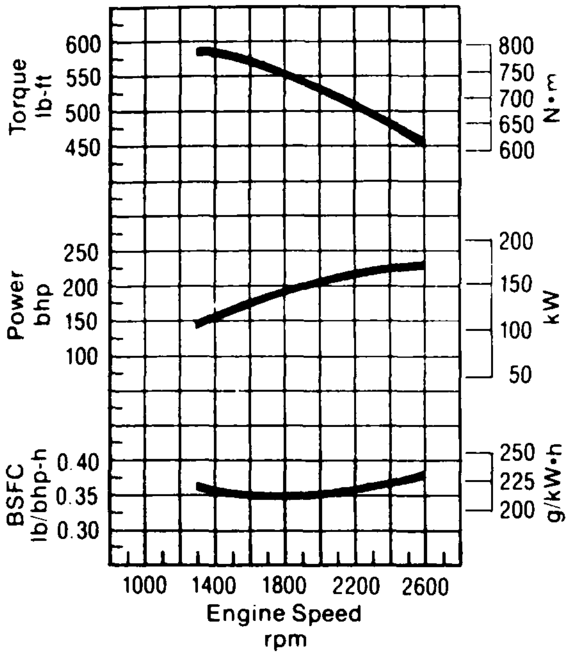
*Engine only. Capacity will vary with radiator size and use of cab heater.

DIMENSIONS



3208—225 hp DIESEL TRUCK ENGINE

PERFORMANCE CURVES



PERFORMANCE DATA

Rated hp (kW)	225 (168)†
Full Load rpm	2600
Low Idle rpm	650
Operating Range (rpm)	1200
Altitude Capability—ft (m)	7,500 (2286)
Peak Torque—lb-ft (N• m)	585 (793)
Peak Torque rpm	1400
Torque Rise	29%
Weight per hp—lb (kg)	6.4 (2.9)

†For on-highway service as defined in 3208 Selection Guide.

*BSFC

The ratio of fuel burned to hp produced is defined as Brake Specific Fuel Consumption (BSFC). The BSFC curve shown above is at full load. While it is a standard industry practice to display rated (full load) BSFC curves, truck engines generally operate a very small portion of the time at full load. Instead, they operate on various part load BSFC curves which are toc numerous to publish. Therefore, predicting fuel consumption from rated (full load) BSFC curves can be misleading. Caterpillar Truck Engines are designed to provide good fuel consumption throughout the entire operating range under both full load and part load conditions. Contact your local Caterpillar representative for further information.

STANDARD EQUIPMENT

- Automatic Variable Timing
- Flywheel and SAE No. 2 Housing
- Fuel Filter (Spin-On)
- Fuel Transfer Pump
- Jacket Water Pump
- Lifting Eyes
- Lube Oil Cooler
- Lube Oil Filters (Spin-On)
- Mechanical Governor (Full-Range)
- Oil Pan (Front or Rear Sump)
- Positive Crankcase Ventilation
- Solenoid Shutoff (12 Volt)
- Supports
- Tachometer Drive (SAE Standard)
- Turbocharger
- Water Separator

OPTIONAL EQUIPMENT

- Air Compressor, 12 cfm (0.34 m^3/min)
- Alternators
    - 12 Volt, 60 Ampere
    - 24 Volt, 40 Ampere
- Auxiliary Pulleys and Drives
- Exhaust Connections
- Fans and Fan Accessories
- Hydraulic Steering Pump Mounting and Drive
- Noise Suppression Equipment
- Solenoid Shutoff (24 Volt)
- Starter (12 or 24 Volt)
- Transmission Mountings

RATING CONDITIONS

Performance is based on SAE J1349 standard conditions of 29.61 in. Hg (100 kPa) and 77 °F (25 °C).

Fuel consumption is based on fuel oil having an HHV of 19,590 Btu/lb (45 570 kJ/kg) and weighing 7.076 lb/U.S. gal (848 g/liter).

The curves shown are for a standard engine without fan, but equipped with fuel, lubricating oil, and jacket water pumps.

Additional ratings may be available for specific customer requirements. Consult your Caterpillar representative for details.

The International System of Units (SI) is used in this publication

Materials and specifications are subject to change without notice

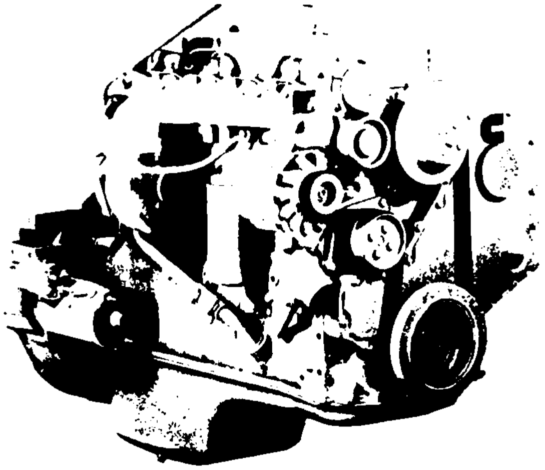
LEHT3097 (11-83)
Supersedes LEHT1589

Caterpillar Cat and are D-55 ks of Caterpillar Tractor Co

Printed in U S A

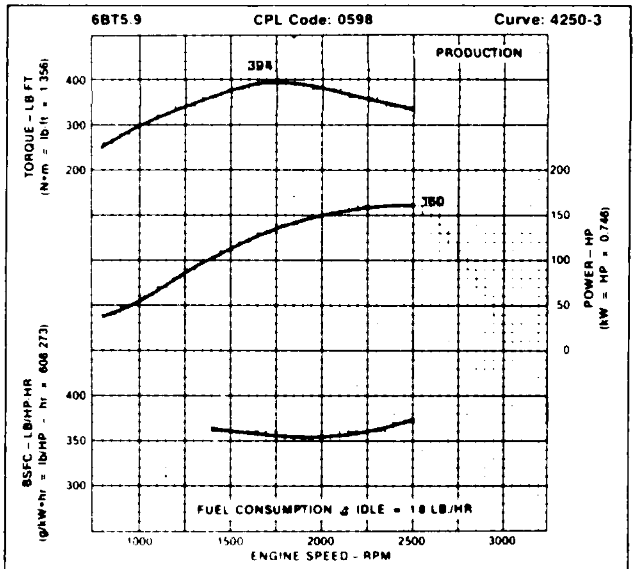
Cummins Diesel Engines

6BT5.9
TRUCK DIESEL



SPECIFICATIONS

Power Rating	119 kW	(160 bhp)
Rated Speed	2500 rpm	(2500 rpm)
Peak Torque (*1700 rpm*)	534 N•m	(394 lb ft)
Nominal Torque Rise	17%	(17%)
Configuration	In-line, 6-cylinder, Direct Injection	
Aspiration	Turbocharged	
Operating Cycles	4	(4)
Clutch Engagement Torque (800 rpm)	407 N•m	(300 lb ft)
Bore and Stroke	102 x 120 mm	(4.02 x 4.72 in.)
Piston Displacement	5.88 L	(359.0 cu. in.)
Compression Ratio	18.5:1	(18.5:1)
Lube System Oil Capacity	16.4 L	(17.3 U.S. qts.)
Coolant Capacity	10.5 L	(11.1 U.S. qts.)
Dry weight with flywheel housing, less flywheel and electrics	399 kg	(880 lb.)
Weight to Power Ratio	3.4 kg/kW	(5.5 lb/hp)



For 4x2 Trucks up to 16,000 kg (35,000 lbs.)
(EPA Certified)

PERFORMANCE: Engine performance at SAE standard J1349 conditions of 99 kPa (29.31 inches Hg) dry barometer, 25°C (77°F) air intake temperature, and 1 kPa (0.30 inches Hg) water vapor pressure with No. 2 diesel fuel will be within ±5% of that shown on a typical engine after break in. Actual performance may vary with different ambient conditions.

Curves represent performance of the engine with water pump, lubricating oil pump, fuel system, and air cleaner; not included are alternator, fan and optional equipment.

6BT5.9
TRUCK DIESEL

DESIGN FEATURES

Cast Iron Skirted Block: With main bearing supports between each cylinder, for maximum strength and rigidity, low weight, and optimum crankshaft support for long life.

Connecting Rods: Drop forged I beam construction for maximum structural strength. Angle split cap-to rod interface and capscrew attachment for ease of service.

Crankshaft: Forged steel with integral counterweights, with main bearing supports between each cylinder, for maximum strength and low weight, to provide long life.

Cylinder Head: Short length cross flow cylinder head for maximum structural strength of the block and head assembly, and to improve combustion, and provide long trouble free life.

Fewer Parts: Less inventory and faster maintenance and repair.

Fuel System: Direct fuel injection, with high swirl intake ports, for better combustion and improved tank fuel mileage.

Parts Simplicity: Enables engines to be serviced and repaired with ordinary hand tools.

Side Mounted Gear Driven Crankshaft: For low engine height.

Single Belt Fan, Alternator, and Water Pump Drive: Self-tensioning idler eliminates maintenance.

Turbocharger: Cummins built HIC turbocharger provides increased power, improved tank mileage, altitude compensation and excellent throttle response. Low mount with exhaust to rear is standard.

Valves: One intake and one exhaust valve for each cylinder with single valve springs.

AVAILABLE EQUIPMENT

Air Compressor: Various compressors direct driven from accessory drive below fuel pump.

Air Intake Accessories: Hump hoses, elbows, and clamps for adapting to various piping sizes.

Accessory Drive Pulley: Mounted on fan hub for driving freon compressor or other accessories.

Alternators: 12 or 24 volt with outputs ranging from 35 to 105 amps.

Exhaust Accessories: Various flanges, connections, and clamps for adapting to exhaust piping.

Fan Drives: Fan centers from 203 mm (8.0 in.) to 444 mm (17.5 in.) and drive ratios of 1:1 and 1.35 times engine speed.

Flywheels: To fit various clutches, torque converters, and transmissions.

Flywheel Housings: Aluminum SAE No. 2 or SAE No. 3 or backing plates for various automotive transmissions.

Freon Compressor Mountings: To fit various rotary and reciprocating compressors.

Front Power Take-off: Pulley and adapters for belt or direct drives.

Front Engine Supports: For single point or barrel mountings.

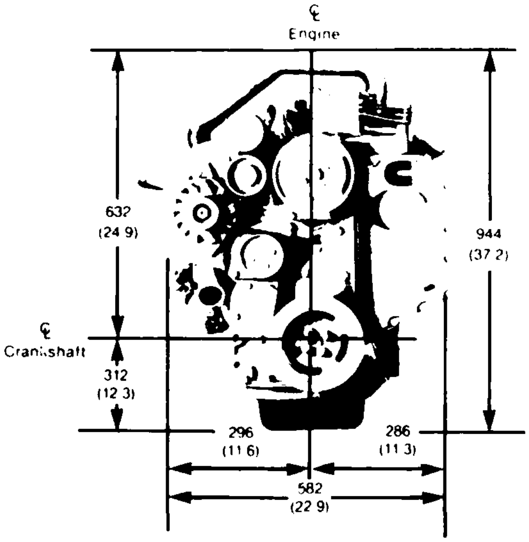
Hydraulic Pump Drives: Direct drive SAE A or SAE B flanges.

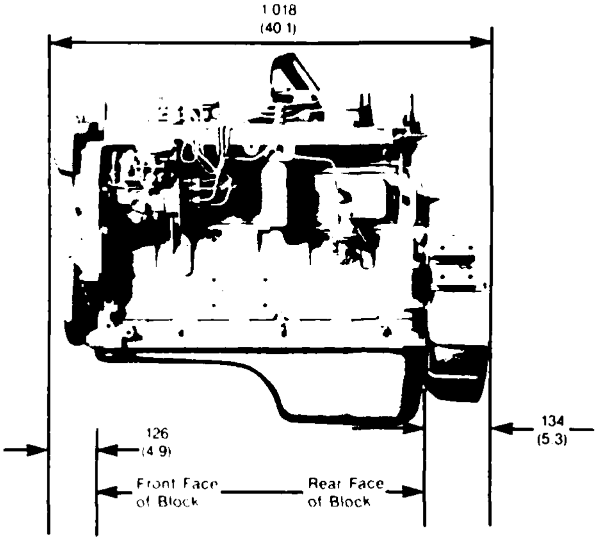
Oil Pans: Front and rear sump types with angularity capability of 45°.

Starters: 12 or 24 volt, positive engagement.

Turbocharger Locations: High mount with exhaust to front or rear, or low mount with exhaust to front.

Water Inlet Connections: Pointing to front 30° down or 73° down, or pointing straight out to side.



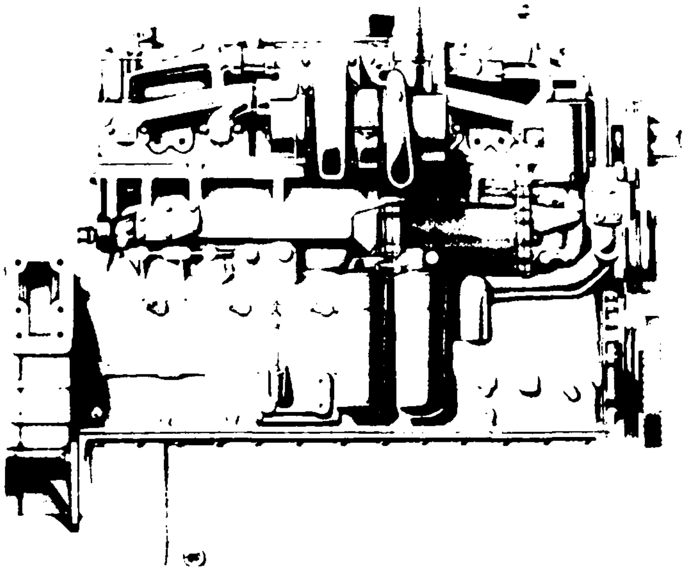


Cummins Engine Company, Inc.
Columbus, Indiana
47202

Cummins has always been a pioneer in product improvement. Thus specifications may change without notice. Illustrations may include optional equipment.

Truck Diesel

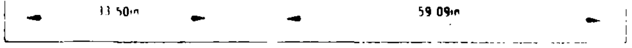
Formula® 240
Power Torque 240



Specifications

		Metric
Power Rating (Formula)	240 bhp	179 kW
Rated Speed	1800 rpm	1800 rpm
Peak Torque (1300 RPM)	900 lb.-ft.	1 220 N•m
Nominal Torque Rise	29%	29%
Power Rating (Power Torque)	240 bhp	179 kW
Rated Speed	2100 rpm	2100 rpm
Peak Torque (1300 RPM)	900 lb.-ft.	1 220 N•m
Nominal Torque Rise	50%	50%
Clutch Engagement Torque (800 RPM)	650 lb.-ft.	881 N•m
Number of Cylinders	6	6
Bore and Stroke	5½ x 6 in.	140 x 152 mm
Piston Displacement	855 cu. in.	14 L
Compression Ratio	15.0:1	15.0:1
Operating Cycles	4	4
†Lube System Oil Cap.	11.0 U.S. gals.	42 L
Coolant Capacity	5.5 U.S. gals.	21 L
Net Weight with Std. Accessories, Dry	2480 lbs.	1 126 kg
Weight at Rated Power	10.3 lbs./hp	6.2 kg/kW
Installation Diagram Number		3035949

†Spin-on full flow and bypass filter are included in total.



Design Features

Camshaft: 2 in. (51 mm) diameter camshaft controls all valve and injector movement. Induction hardened alloy steel with gear drive. Crowned roller camshaft followers for long camshaft and follower life.

Connecting Rods: Drop forged, 12 in. (305 mm) center to center length. Rifle drilled for pressure lubrication of piston pin. Taper piston pin end reduces bearing pressures.

Corrosion Resistor: Spin-on type, mounted. Checks rust and corrosion, controls acidity, and removes impurities from coolant.

Crankshaft: High tensile strength steel forging. Bearing journals and fillets are induction hardened. Fully counterweighted.

Cylinder Block: Alloy cast iron with removable, wet liners.

Cylinder Heads: Each head serves two cylinders. Drilled fuel supply and return lines. High temperature and wear resistant inserts on intake and exhaust valve seats.

Exhaust Manifold: Pulse type design for less restricted and more energy efficient exhaust flow to the turbocharger.

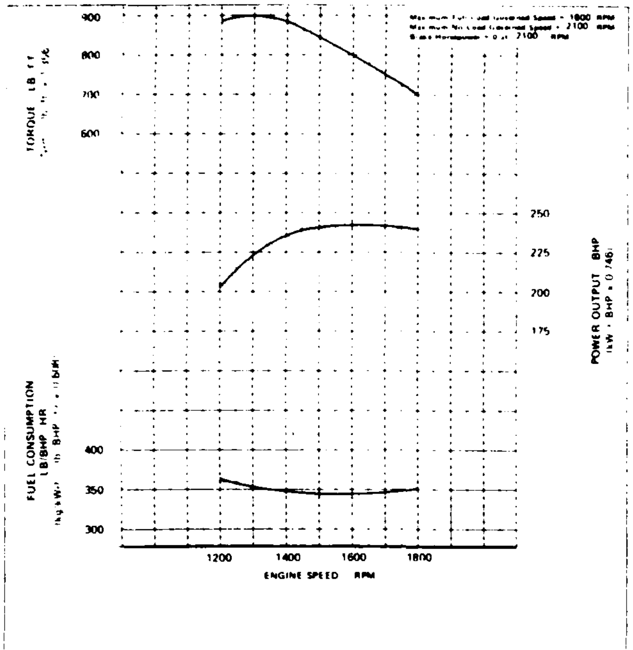
Filters: Lubricating oil; spin-on paper element full flow, and spin-on stacked disc bypass, mounted to oil cooler. Fuel; super filter spin-on paper element engine mounted. Water; spin-on paper element, corrosion inhibitor.

Fuel System: Cummins PT™ wear-compensating system with integral governor. Camshaft actuated Top Stop injectors.

Lubricating Oil Cooler: Tube and fin type, two pass water cooled with spin-on full flow and by-pass filters. Temperature controlled by-pass circuit to maintain oil temperature. Integral pressure relief valve and low oil pressure/full flow filter restriction alarm.

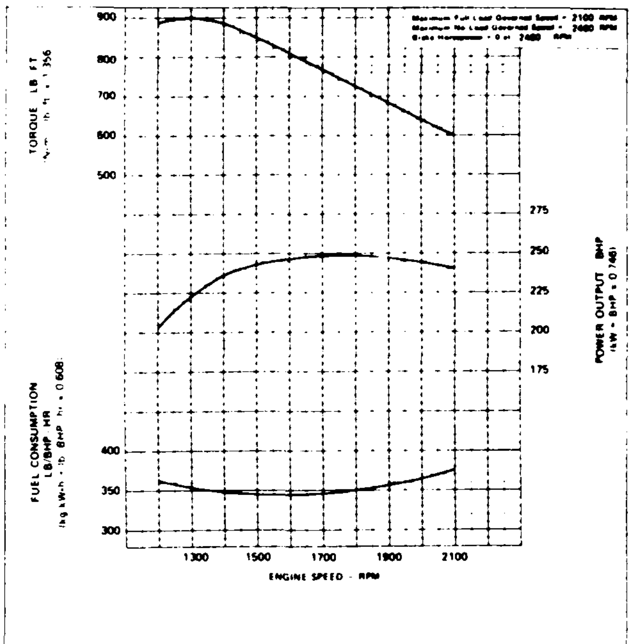
Design Features continued on back page.

Formula' 240 **1800 RPM**



Performance Curve: C-4109-A **CPL Code: 0497**

Power Torque 240 **2100 RPM**



Performance Curve: CO-4085-2 **CPL Code: 0497**

Design Features Continued

Lubrication: Force feed to all bearings, gear type pump with pressure regulation from main bearing oil supply galley.

Thermostat: Single ventless, modulating by-pass type; low leakage, can be used with shutterless cooling system.

Turbocharger: Cummins manufactured T-46.

Valves: Dual intake and exhaust each cylinder. Each valve 1⅞ in. (47 mm) diameter. High temperature and wear resistant face on exhaust valve.

Water Pump: Poly-vee belt driven, centrifugal type.

Available Equipment

Air Compressor: Cummins 13.2 CFM (374 L/min.) one cylinder, coupling driven and pressure charged; 30 CFM (850 L/min.) two cylinder.

Electrical Equipment: 12 and 24 volt starter; 12 and 24 volt alternators of various ampere outputs.

Fan Mounting: Bracket mounted hub and pulley. Hub 20¼ in. (514 mm) above crankshaft.

Flywheel: For various 14 in. (356 mm) and 15½ in. (394 mm) automotive clutches.

Flywheel Housing: S.A.E. No. 1 or 2 cast aluminum with mounting pads.

Front Mounting: Provision for pad type engine support, or 6 in. (152 mm) diameter trunnion.

Governor: Limiting speed or variable speed, dual flyweight with single or dual throttle controls.

Oil Pan: Stamped steel rear sump, cast aluminum front sump, 9 U.S. gallon (34.0 L) capacity.

Steering Pump Drive: Coupling driven, two bolt flange mounting at rear of lube pump..

Other Optional Accessories: Can be provided by Cummins upon request to fit special applications.

Performance

Engine performance at SAE standard J816b conditions of 500 ft. (150 m) altitude (29.00 inches [736 mm] Hg dry barometer), 85°F (29°C) air intake temperature, and 0.38 inches (9.6 mm) Hg water vapor pressure with No. 2 diesel fuel will be within 5% of that shown at the time of engine shipment. Actual performance may vary with different ambient conditions.

Curves represent performance of the engine with water pump, lubricating oil pump, fuel system, compressor (unloaded) and air cleaner; not included are alternator, fan and optional equipment.

Conversion Factors to Metric:

Torque	lb.-ft.	x 1.356 = ________	N•m
Power	bhp	x .746 = ________	kW
Fuel	lb./bhp-hr.	x .608 = ________	kg/kW-hr.

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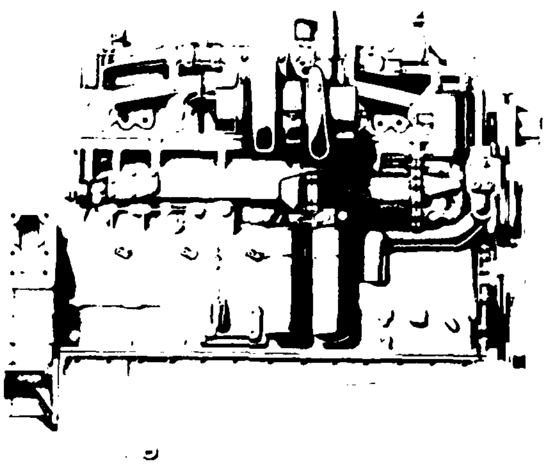
Cummins Engine Company, Inc., Columbus, Indiana 47202

FORMULA® 270
POWER TORQUE 270
TRUCK DIESEL



SPECIFICATIONS

Power Rating **(Formula)**	201 kW	(270 bhp)
Rated Speed	1800 rpm	(1800 rpm)
Peak Torque (1300 rpm)	1 356 N•m	(1 000 lb-ft)
Nominal Torque Rise	27%	(27%)
Power Rating **(Power Torque)**	201 kW	(270 bhp)
Rated Speed	2100 rpm	(2100 rpm)
Peak Torque (1300 rpm)	1 356 N•m	(1 000 lb-ft)
Nominal Torque Rise	48%	(48%)
Clutch Engagement Torque (800 rpm)	814 N•m	(600 lb-ft)
Number of Cylinders	6	(6)
Bore and Stroke	140x152 mm	(5½x6 in.)
Piston Displacement	14 L	(855 cu. in.)
Compression Ratio	15.0:1	(15.0:1)
Operating Cycles	4	(4)
†Oil System Cap.	42 L	(11 U.S. gals.)
Coolant Capacity	21 L	(5.5 U.S. gals.)
Net Weight with Std. Accessories, Dry	1 130 kg	(2 490 lbs.)
Weight at Rated Power	5.6 kg/kW	(9.2 lb/hp)
Installation Diagram Number		3035950

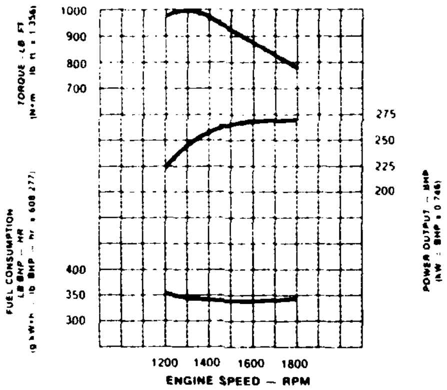
†Spin on full flow and by-pass filter are included in total.

PERFORMANCE:

Horsepower, torque, and fuel consumption curves represent performance at SAE standard *J816b conditions of 150 m (500 ft) altitude (736 mm [29.00* inches] Hg Dry Barometer), 29 C (85 F) intake air temperature, and 9.6 mm (0.38 inches) Hg water vapor pressure.

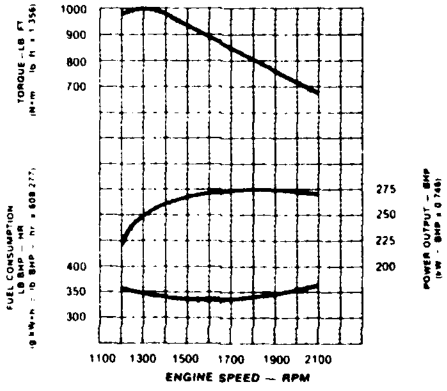
Curves represent performance of the engine with water pump, lubricating oil pump, fuel system, muffler, and air cleaner; not included are alternator, fan, compressor, and optional equipment. Curves represent performance with No. 2 diesel or a fuel corresponding to ASTM D2.

Formula 270 CPL Code 0579 Curve C-4190



Maximum Full Load Governed Speed = 1800 RPM
Maximum No Load Governed Speed = 2050 RPM
Brake Horsepower = 0 at 2050 RPM

Power Torque 270 CPL Code 0579 Curve: CO-4190-1



Maximum Full Load Governed Speed = 2100 RPM
Maximum No Load Governed Speed = 2390 RPM
Brake Horsepower = 0 at 2390 RPM

FORMULA® 270
POWER TORQUE 270
TRUCK DIESEL

DESIGN FEATURES

Camshaft: Large 64 mm (2½ in.) diameter camshaft controls all valve and injector movement. Induction hardened alloy steel with gear drive. Crowned roller type camshaft followers for long cam and follower life.

Connecting Rods: Drop forged, 305 mm (12 in.) center to center length. Rifle drilled for pressure lubrication of piston pin. Taper piston pin end reduces bearing pressures.

Crankshaft: High tensile strength steel forging. Bearing journals and fillets are induction hardened. Fully counterweighted.

Cylinder Block: Alloy cast iron with removable, wet liners.

Cylinder Heads: Each head serves two cylinders. Drilled fuel supply and return lines. High temperature and wear resistant inserts on exhaust valve seats.

Exhaust Manifold: Pulse type design for less restricted and more energy efficient exhaust flow to the turbocharger.

Filters: Lubricating oil, spin on paper element, full flow, and spin on stacked disc by-pass, mounted to oil cooler. Fuel *spin-on paper element, engine mounted. Filters manufac*tured by Fleetguard, a division of Cummins Engine Company, Inc.

Fuel System: Cummins PT™ wear compensating system with integral flyweight type governor. Camshaft actuated Top Stop injectors.

Lubricating Oil Cooler: Tube and fin type, two pass water cooled with spin-on full flow and by-pass filters. Temperature controlled by-pass circuit to maintain oil temperature. Integral pressure relief valve and low oil pressure full flow filter restriction alarm.

Lubrication: Force feed to all bearings, gear type pump with pressure regulation from main bearing oil supply gallery.

Thermostat: Single unit, modulating by-pass type, low leakage, can be used with shutterless cooling system.

Turbocharger: Cummins manufactured T46B.

Valves: Dual intake and exhaust each cylinder. Each valve 47 mm (1⅞ in.) diameter. High temperature and wear *resistant face on exhaust valve.*

Water Pump: Centrifugal type, vee ribbed belt driven, with volute type housing cast in block.

AVAILABLE EQUIPMENT

Air Compressor: Cummins 374 L/min (13.2 CFM) one cylinder, 850 L/min (30 CFM) two cylinder, coupling driven and pressure charged.

Corrosion Resistor: Spin on type, mounted. Checks rust and corrosion, controls acidity, and removes impurities from coolant.

Electrical Equipment: 12 and 24 volt starter; 12 and 24 volt alternators of various ampere outputs.

Fan Mounting: Bracket mounted hub and pulley.

Flywheel: For various 356 mm (14 in.) and 394 mm (15½ in.) automotive clutches.

Flywheel Housing: SAE No. 1 or 2 cast aluminum with mounting pads.

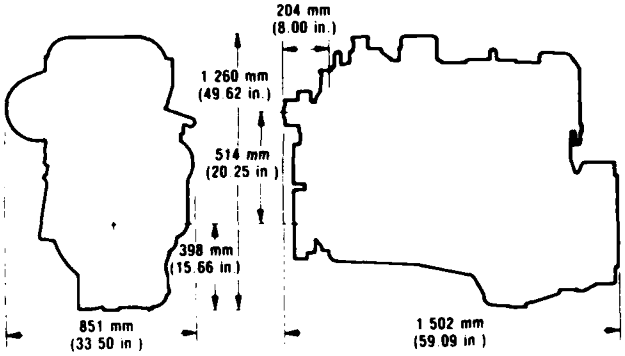
Front Mounting: Provision for pad type engine support or 152 mm (6 in.) diameter trunnion.

Governor: Limiting speed or variable speed, dual flyweight with single or dual throttle controls.

Oil Pan: Stamped steel rear sump, cast aluminum front sump. 34.0 L (9 U.S. gallon) capacity.

Steering Pump Drive: Coupling driven, two bolt flange mounting at rear of lube pump.

Other Optional Accessories: Can be provided by Cummins to fit special applications.



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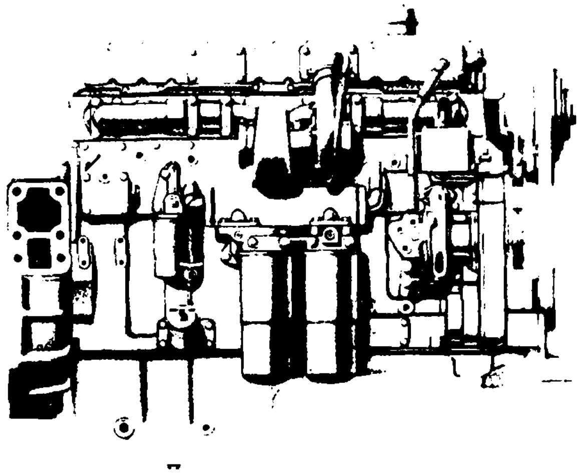
Cummins Engine Company, Inc.
Columbus, Indiana
47202

Bulletin 3380533 (BC III)   Printed in U.S.A.   Rev. 7/84

POWER TORQUE L10-285
TRUCK DIESEL

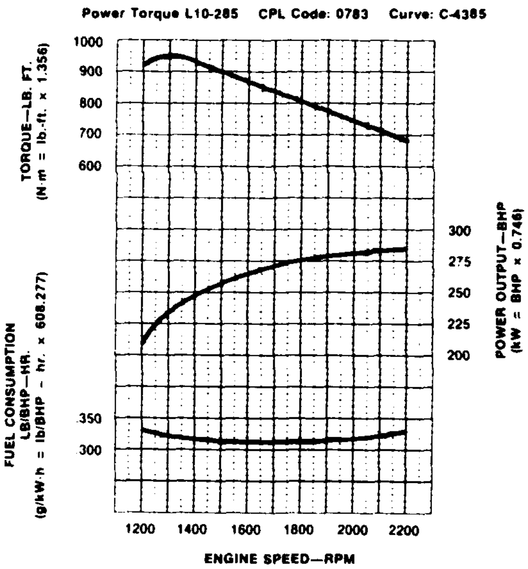
OPTIMIZED AFTERCOOLING



SPECIFICATIONS

Power Rating	285 bhp	(213 kW)
Rated Speed	2200 rpm	(2200 rpm)
Peak Torque (1300 rpm)	950 lb.-ft.	(1 288 N•m)
Nominal Torque Rise	40%	(40%)
Clutch Engagement Torque (800 rpm)	550 lb.-ft.	(746 N•m)
Number of Cylinders	6	(6)
Bore and Stroke	4.921x5.354 in.	(125x136 mm)
Piston Displacement	611 cu. in.	(10 L)
Compression Ratio	16.3:1	(16.3:1)
Operating Cycles	4	(4)
†Oil System Cap.	9 U.S. gals.	(34 L)
Coolant Capacity	12 qts.	(11 L)
Net Weight with Std. Accessories, Dry	1,930 lbs.	(876 kg)
Weight at Rated Power	6.77 lbs./hp	(4.1 kg/kW)
Installation Diagram Number		3042762

†Spin-on full flow and by-pass filters are included in total.



Maximum Full Load Governed Speed = 2200 RPM
Maximum No Load Governed Speed = 2570 RPM
Brake Horsepower = 0 at 2570 RPM

PERFORMANCE:

Engine performance at SAE standard J1349 conditions of 300 ft. (90 m) altitude (29.61 inches Hg [100 kPa] barometric pressure), 77°F (25°C) air intake temperature, and 0.30 inches Hg (1 kPa) water vapor pressure with No. 2 diesel fuel will be within 5% of that shown at the time of engine shipment. Actual performance may vary with different ambient conditions.

Curves represent performance of the engine with fuel system, water pump, lubricating oil pump, air compressor (unloaded), and with 10 in. H_2O (250 mm) inlet air restriction and with 2.0 in. Hg (50 mm) exhaust restriction, not included are alternator, fan, optional equipment and driven components.

POWER TORQUE L10-285
TRUCK DIESEL

DESIGN FEATURES

Air Intake System: Optimized aftercooling provides cooler air to the cylinders for improved fuel economy, faster response, and reduced internal temperature for increased durability.

Aftercooler: New aftercooler with two pass coolant flow and larger core yields higher effectiveness and lower air inlet temperature.

Bearings: Exceptionally large steel-backed tri-metal bearings throughout engine provide long engine life.

Camshaft: High location in the block, large 2.83 in. (72 mm) diameter cam permits short, stiff injector train for precise fuel metering and high injection pressures, resulting in excellent fuel economy. Crowned cam follower rollers provide long cam and follower life.

Connecting Rods: Drop forged, I-beam construction for strength. Tapered piston pin end provides stronger piston pin bore for durability. Short 8.58 in. (218 mm) length reduces overall engine height.

Crankshaft: Induction hardened for strength. Large 4.5 in. (114 mm) main bearings for durability. Eight counterweights instead of twelve reduce engine weight while providing full engine balance.

Cylinder Head: One-piece cylinder head reduces engine length and provides a rigid head-to-block fit. Ports are oriented to provide free intake and exhaust flow; short exhaust ports provide low heat rejection.

Cylinder Liners: Mid-stop, shortened water jacket length reduces heat rejection to the coolant and provides more consistent liner/block sealing. New liner clamping technique minimizes liner vibration.

Exhaust Manifold: Pulse design reduces back pressure for better fuel economy and more efficient exhaust flow to the turbocharger for outstanding throttle response and driveability.

Filters: Engine mounted, FLEETGUARD spin-on full flow and bypass oil filters, coolant, and fuel filters eliminate external brackets and plumbing and provide cleaner, faster serviceability.

Fuel System: Cummins PT® wear-compensating system. Camshaft actuated Top Stop injectors. Direct throttle control for maximum driving ease.

Gear Driven Components: Induction hardened helical gears drive all base engine components, including water pump, lube pump, camshaft, fuel pump, air compressor, hydraulic pump and two fan options.

Integral Air Manifold: Integral intake manifolding, using the *aftercooler housing and rocker housing,* provides intake and exhaust gas handling on same side of engine eliminating need for air crossover and separate intake manifold to reduce engine height and improve responsiveness.

Lube Oil Cooler: Unitized design provides full flow oil cooling for high effectiveness and light weight.

Lubrication: Positive pressure lubrication to all moving parts, including bearings, gears, and overhead assemblies for long life; piston cooling for reliability and durability.

Piston: High top ring piston with three rings, two chrome faced compression rings and a two-piece dual rail oil control ring. High top ring provides efficient combustion and good response.

Steering Pump Drive: Gear driven with SAE A two bolt flange mounting.

Thermostat: New design maintains correct engine coolant temperature and controls engine intake air temperature for fuel efficiency.

Turbocharger: *Cummins built H2C turbo featuring divided* turbine casing which provides improved exhaust gas handling for faster throttle response and short aerodynamic ports.

Valves: Dual intake and exhaust each cylinder. Generous valve area for less restricted gas flow for improved combustion and fuel economy.

Vibration Damper: Viscous damper located inside front cover.

Water Pump: Centrifugal type, with volute type housing. Water pump is easily removed from back side of gear housing for service without disturbing radiator or other front end components.

AVAILABLE EQUIPMENT

Air Compressor: Cummins 13.2 CFM (374 L/min.) one cylinder, coupling driven and pressure charged; 30 CFM (850 L/min.) two cylinder coupling driven and naturally aspirated.

Electrical Equipment: 12 volt and 24 volt starter; 12 and 24 volt alternators of various ampere outputs.

Fan Mounting: Poly-vee belt driven at .8 times engine speed. Hub 17 in. (432 mm) above crankshaft. Other fan hub spacings and speeds available.

Flywheel: For various 14 in. (356 mm) and 15½ in. (394 mm) automotive clutches.

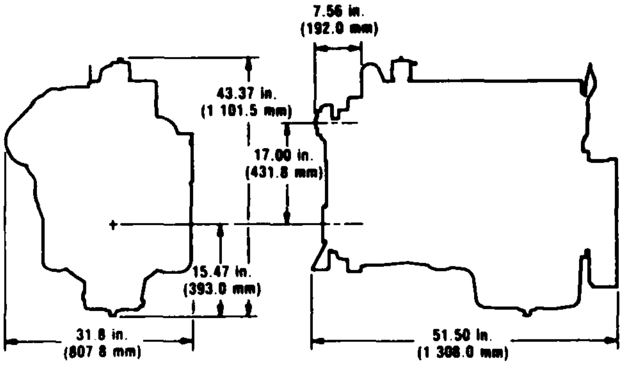
Flywheel Housing: SAE No. 1 and 2 cast aluminum with mounting pads.

Front Mounting: Pad type engine support.

Governor: Limiting speed or variable speed, dual flyweight with single or dual throttle controls.

Oil Pan: Stamped steel, 7 U.S. gallon (26.5 L) capacity, optional sump locations; (front and rear).

Other Optional Accessories: Can be provided by Cummins to fit special applications.



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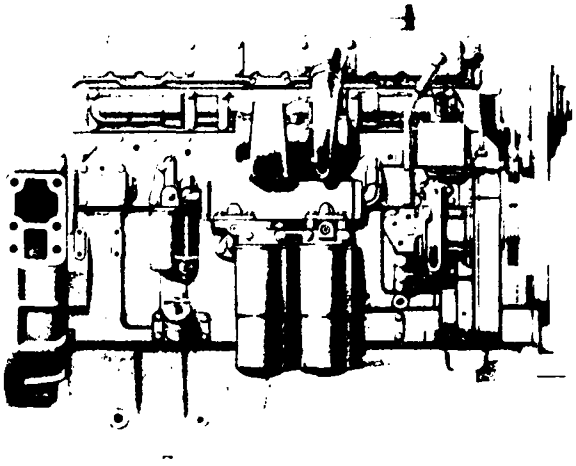
Cummins Engine Company, Inc.
Columbus, IN 47202
U.S.A.

Bulletin 3380679 Printed in U.S.A. 3/86

FORMULA® L10-300
L10-300
TRUCK DIESEL

OPTIMIZED AFTERCOOLING



SPECIFICATIONS

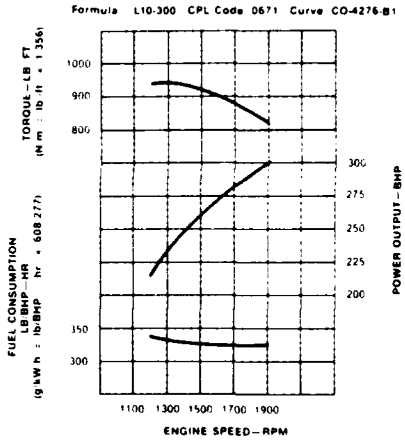
Power Rating (Formula®)	**300 bhp**	**(224 kW)**
Rated Speed	1900 rpm	(1900 rpm)
Peak Torque (1300 rpm)	950 lb.-ft.	(1 288 N•m)
Nominal Torque Rise	15%	(15%)
Power Rating (L10-300)	**300 bhp**	**(224 kW)**
Rated Speed	2100 rpm	(2100 rpm)
Peak Torque (1300 rpm)	950 lb.-ft.	(1 288 N•m)
Nominal Torque Rise	27%	(27%)
Clutch Engagement Torque (800 rpm)	550 lb.-ft.	(746 N•m)
Number of Cylinders	6	(6)
Bore and Stroke	4.921x5.354 in.	(125x136 mm)
Piston Displacement	611 cu. in.	(10 L)
Compression Ratio	16.3:1	(16.3:1)
Operating Cycles	4	(4)
†Oil System Cap.	9 U.S. gals.	(34 L)
Coolant Capacity	12 qts.	(11 L)
Net Weight with Std. Accessories, Dry	1,930 lbs.	(876 kg)
Weight at Rated Power	6.4 lbs./hp	(3.9 kg/kW)
Installation Diagram Number		3042762

†Spin-on full flow by-pass filters are included in total.

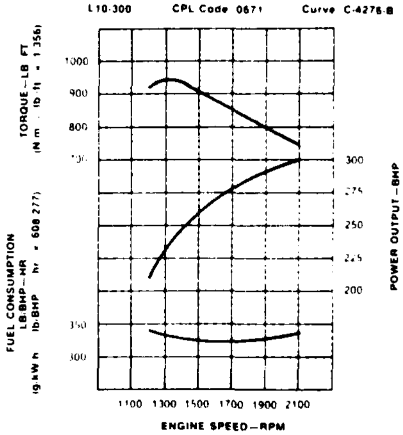
PERFORMANCE:

Engine performance at SAE standard J1349 conditions of 300 ft (90 m) altitude (29.61 inches Hg [100 kPa] barometric pressure) 77°F (25°C) air intake temperature, and 0.30 inches Hg (1 kPa) water vapor pressure with No. 2 diesel fuel will be within 5% of that shown at the time of engine shipment. Actual performance may vary with different ambient conditions.

Curves represent performance of the engine with fuel system, water pump, lubricating oil pump, air compressor (unloaded); and with 10 in. H_2O (250 mm) inlet air restriction and with 2.0 in. Hg (50 mm) exhaust restriction; not included are alternator, fan, optional equipment and driven components.



Maximum Full Load Governed Speed = 1900 RPM
Maximum No Load Governed Speed = 2220 RPM
Brake Horsepower = 0 at 2220 RPM



Maximum Full Load Governed Speed = 2100 RPM
Maximum No Load Governed Speed = 2460 RPM
Brake Horsepower = 0 at 2460 RPM

FORMULA® L10-300
L10-300
TRUCK DIESEL

DESIGN FEATURES

Air Intake System: Optimized aftercooling provides cooler air to the cylinders for improved fuel economy, faster response, and reduced internal temperature for increased durability.

Aftercooler: New aftercooler with two pass coolant flow and larger core yields higher effectiveness and lower air inlet temperature.

Bearings: Exceptionally large steel-backed tri-metal bearings throughout engine provide long engine life.

Camshaft: High location in the block, large 2.83 in. (72 mm) diameter cam permits short, stiff injector train for precise fuel metering and high injection pressures, resulting in excellent fuel economy. Crowned cam lobes and cam follower rollers provide long cam and follower life.

Connecting Rods: Drop forged, I-beam construction for strength. Tapered piston pin end provides stronger piston pin bore for durability. Short 8.58 in. (218 mm) length reduces overall engine height.

Crankshaft: Induction hardened for strength. Large 4.5 in. (114 mm) main bearings for durability. Eight counterweights instead of twelve reduce engine weight while providing full engine balance.

Cylinder Head: One-piece cylinder head reduces engine length and provides a rigid head-to-block fit. Ports are oriented to provide free intake and exhaust flow; short exhaust ports provide low heat rejection.

Cylinder Liners: Mid-stop, shortened water jacket length reduces heat rejection to the coolant and provides more consistent liner/block sealing. New liner clamping technique minimizes liner vibration.

Exhaust Manifold: Pulse design reduces back pressure for better fuel economy and more efficient exhaust flow to the turbocharger for outstanding throttle response and driveability.

Filters: Engine mounted, FLEETGUARD spin-on full flow and bypass oil filters, coolant, and fuel filters eliminate external brackets and plumbing and provide cleaner, faster serviceability.

Fuel System: Cummins PT™ wear-compensating system. Camshaft actuated PTD injectors. Direct throttle control for maximum driving ease.

Gear Driven Components: Induction hardened helical gears drive all base engine components, including water pump, lube pump, camshaft, fuel pump, air compressor, hydraulic pump and two fan options.

Integral Air Manifold: Integral intake manifolding, using the aftercooler housing and rocker housing, provides intake and exhaust gas handling on same side of engine, eliminating need for air crossover and separate intake manifold to reduce engine height and improve responsiveness.

Lube Oil Cooler: Unitized design provides full flow oil cooling for high effectiveness and light weight.

Lubrication: Positive pressure lubrication to all moving parts, including bearings, gears, and overhead assemblies for long life; piston cooling for reliability and durability.

Piston: High top ring piston with three rings, two chrome faced compression rings and a two-piece dual-rail oil control ring. High top ring provides efficient combustion and good response.

Steering Pump Drive: Gear driven with SAE A two bolt flange mounting.

Thermostat: New design maintains correct engine coolant temperature and controls engine intake air temperature for fuel efficiency.

Turbocharger: Cummins built H2C turbo featuring divided turbine casing *which provides improved* exhaust gas handling for faster throttle response and short *aerodynamic ports*.

Valves: Dual intake and exhaust each cylinder. Generous valve area for less restricted gas flow for improved combustion and fuel economy.

Vibration Damper: Viscous damper located inside front cover.

Water Pump: Centrifugal type with volute type housing. Water pump is easily removed from back side of gear housing for service without disturbing radiator or other front end components.

AVAILABLE EQUIPMENT

Air Compressor: Cummins 13.2 CFM (374 L/min.) one cylinder, coupling driven and pressure charged; 30 CFM (850 L/min.) two cylinder coupling driven and naturally aspirated.

Electrical Equipment: 12 volt and 24 volt starter, 12 and 24 volt alternators of various ampere outputs.

Fan Mounting: Poly-vee belt driven at .8 times engine speed. Hub 17 in. (432 mm) above crankshaft. Other fan hub spacings and speeds available.

Flywheel: For various 14 in. (356 mm) and 15½ in. (394 mm) automotive clutches.

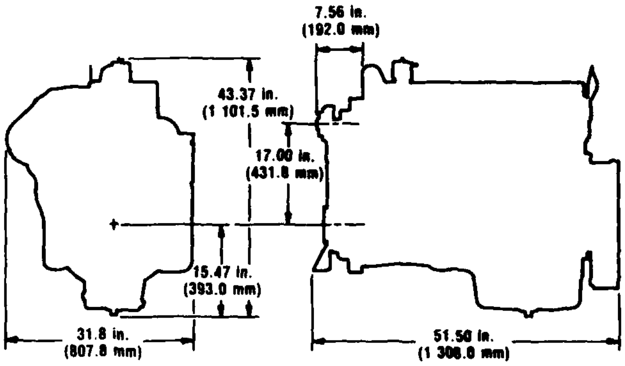
Flywheel Housing: SAE No. 1 and 2 cast aluminum with *mounting pads*.

Front Mounting: Pad type engine support.

Governor: Limiting speed or variable speed, dual flyweight with single or dual throttle controls.

Oil Pan: Stamped steel, 7 U.S. gallon (26.5 L) capacity, optional sump locations; front and rear.

Other Optional Accessories: Can be provided by Cummins to fit special applications.



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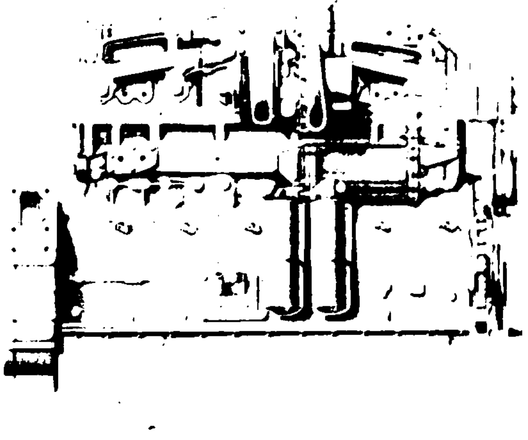
Cummins Engine Company, Inc.
Columbus, IN 47202
U.S.A.

Bulletin 3380579 Printed in U.S.A. Rev. 6/85

FORMULA® 300
NTC-300
BIG CAM IV
TRUCK DIESEL



SPECIFICATIONS

Power Rating **(Formula 300)**	224 kW	(300 bhp)
Rated Speed	1800 rpm	(1800 rpm)
Peak Torque (1300 rpm)	1 356 N•m	(1000 lb-ft.)
Nominal Torque Rise	14%	(14%)
Power Rating **(NTC-300)**	224 kW	(300 bhp)
Rated Speed	2100 rpm	(2100 rpm)
Peak Torque (1300 rpm)	1 356 N•m	(1000 lb.-ft.)
Nominal Torque Rise	33%	(33%)
Clutch Engagement Torque (800 rpm)	814 N•m	(600 lb.-ft.)
Number of Cylinders	6	(6)
Bore and Stroke	140 x 152 mm	(5½ x 6 in.)
Piston Displacement	14 L	(855 cu. in.)
Compression Ratio	15.5:1	(15.5:1)
Operating Cycles	4	(4)
†Lube System Oil Cap.	42 L	(11.0 U.S. gals.)
Coolant Capacity	21 L	(5.5 U.S. gals.)
Net Weight with Std. Accessories, Dry	1 149 kg	(2,530 lbs.)
Weight at Rated Power	5.1 kg/kW	(8.4 lbs./hp)
Installation Diagram Number		3041462

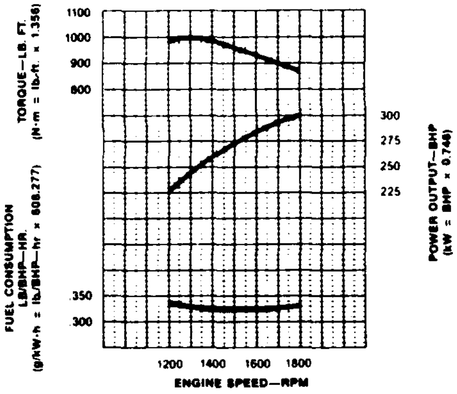
†Spin-on full flow and by-pass filters are included in total.

PERFORMANCE

Engine performance at SAE standard J1349 conditions of 90 m (300 ft) altitude (100 kPa [29.61 inches Hg] barometric pressure), 25 °C (77 °F) air intake temperature, and 1 kPa (0.30 inches Hg) water vapor pressure with No. 2 diesel fuel will be within 5% of that shown at the time of engine shipment. Actual performance may vary with different ambient conditions.

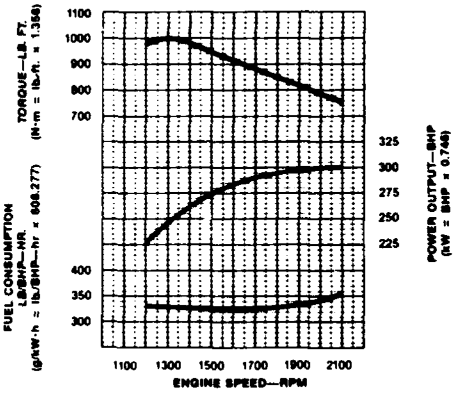
Curves represent performance of the engine with fuel system, water pump, lubricating oil pump, air compressor (unloaded), and with 250 mm (10 in.) H_2O inlet air restriction and with 50 mm (2.0 in.) Hg exhaust restriction; not included are alternator, fan, optional equipment and driven components.

Formula 300 CPL Code: 0674 Curve C-4295-A



Maximum Full Load Governed Speed = 1800 RPM
Maximum No Load Governed Speed = 2050 RPM
Brake Horsepower = 0 at 2050 RPM

NTC-300 CPL Code: 0674 Curve: CO-4295-A1



Maximum Full Load Governed Speed = 2100 RPM
Maximum No Load Governed Speed = 2390 RPM
Brake Horsepower = 0 at 2390 RPM

FORMULA® 300
NTC-300
BIG CAM IV
TRUCK DIESEL

DESIGN FEATURES

Aftercooling: Air to water low temperature aftercooling for improved fuel consumption and reduced emissions. Other advantages are smaller energy loss, lower cylinder temperatures, lower exhaust temperatures and improved combustion which results in improved engine durability. Centered intake manifold aftercooler core assembly with two pass coolant flow for high efficiency. Frontal crossover air intake improves overhead servicing.

Camshaft: 64 mm (2½ in.) diameter camshaft provides improved fuel economy with a fast opening cam profile and increased valve lift. Induction hardened alloy steel with helical gear drive controls injection movement. Crown cam follower rollers provide long cam and follower life.

Compuchek: Provision for easy application of Compuchek.

Connecting Rods: Drop forged, 305 mm (12 in.) center to center length. Rifle drilled for pressure lubrication of piston pin. Taper piston pin end reduces bearing pressures.

Corrosion Resistor: Integral part of the thermostat housing with spring loaded check valves. Spin-on type, checks rust and corrosion, controls acidity and filters impurities from the coolant.

Crankshaft: High tensile strength steel forging. Bearing journals and fillets are induction hardened. Fully counterweighted.

Cylinder Block: Alloy cast iron with removable wet liners.

Cylinder Heads: Each head serves two cylinders. Drilled fuel supply and return lines. High temperature and wear resistant inserts on intake and exhaust valve seats.

Exhaust Manifold: Pulse type design for less restricted and more energy efficient exhaust flow to the turbocharger.

Filters: Fleetguard. Lubricating oil: spin-on paper element full flow, and spin-on stacked disc by-pass, mounted to oil cooler. Fuel: SUPERFILTER spin-on paper element engine mounted. Water: spin-on paper element engine mounted, corrosion inhibitor.

Fuel System: Cummins PT™ wear-compensating system with integral governor. Camshaft actuated Top Stop injectors.

Lubricating Oil Cooler: Tube and fin type, two pass water cooled with spin-on full flow and by-pass filters. Temperature controlled by-pass circuit to maintain oil temperature. Integral pressure relief valve and low oil pressure/full flow filter restriction alarm.

Lubrication: Force feed to all bearings, gear type pump with pressure regulation from main bearing oil supply galley.

Oil Pan: Stamped steel rear sump, cast aluminum front sump, 34.0 L (9 U.S. gallon) capacity.

Steering Pump Drive: Coupling driven, two bolt flange mounting at rear of lube pump.

Thermostats: Dual ventless thermostats to provide precise metering of by-pass and radiator flow. The single function valves feature removable seats for improved sealing and reduced movement for longer life.

Turbocharger: Cummins manufactured HT3B, single entry.

Valves: Dual intake and exhaust each cylinder. Each valve 47 mm (1⅞ in.) diameter. High temperature and wear resistant face on exhaust valve.

Water Pump: High flow poly-vee driven centrifugal type with volute type housing cast in block provides both constant recirculating flow through the block and variable flow through the radiator.

AVAILABLE EQUIPMENT

Air Compressor: Cummins 374 L/min. (13.2 CFM) one cylinder, coupling driven and pressure charged; 850 L/min. (30 CFM) two cylinder.

Block Heater: 1500 watts, 115 volts, with grounded 3 pin plug.

Electrical Equipment: 12 and 24 volt starter. 12 and 24 volt alternators of various ampere outputs.

Fan Mounting: Bracket mounted hub and pulley.

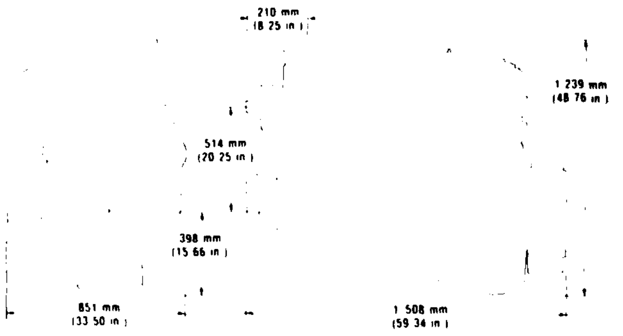
Flywheel: For various 356 mm (14 in.) and 394 mm (15½ in.) automotive clutches.

Flywheel Housing: S.A.E. No. 1 or 2 cast aluminum with mounting pads.

Front Mounting: Provision for pad type engine support, or 152 mm (6 in.) diameter trunnion.

Governor: Limiting speed or variable speed, dual flyweight with single or dual throttle controls.

Other Optional Accessories: Can be provided by Cummins upon request to fit special applications.



Cummins has always been a pioneer in product improvement. Thus specifications may change without notice. Illustrations may include optional equipment.

Cummins Engine Company, Inc.
Columbus, Indiana
47202

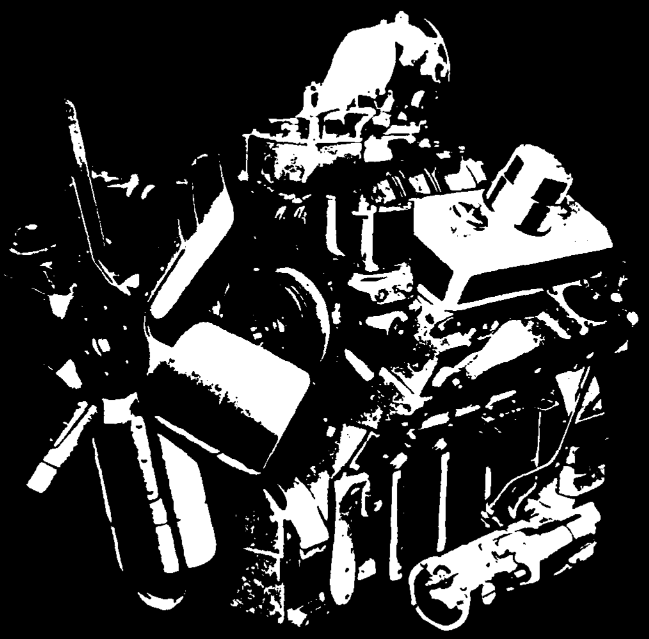
Bulletin 3380562 (BC IV) Printed in USA 7/84

Detroit Diesel Engines

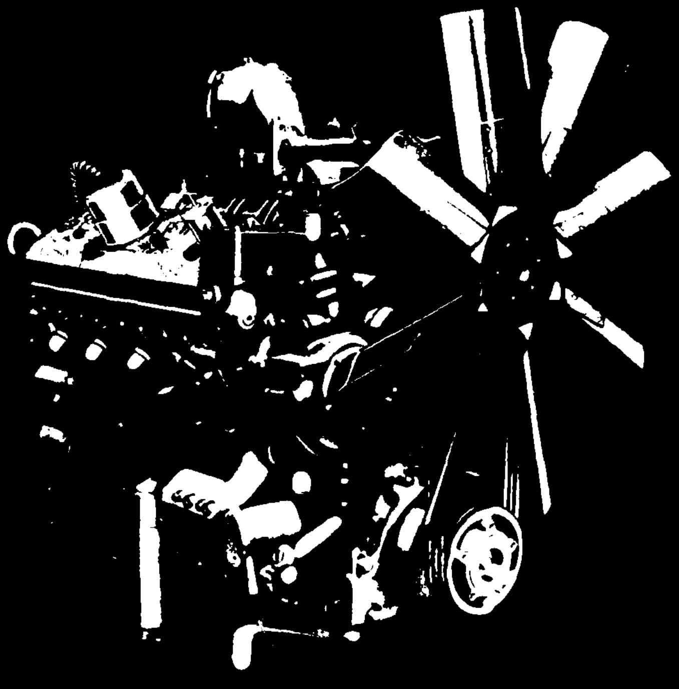
Detroit Diesel Engines fan-to-flywheel models

POWER [illegible]
90 [illegible]
WAKEFIELD, [illegible]
617-[illegible]

6V-92	6V-92T	6V-92TA	8V-92	8V-92T	8V-92TA
288 hp	330 hp	345 hp	384 hp	435 hp	450 hp



Typical 6V-92
Fan-To-Flywheel Model



Typical 8V-92
Fan-To-Flywheel Model

Basic Engine	**6V-92** **9285 Injectors**	**6V-92T** **9B90 Injectors**	**6V-92TA** **9B90 Injectors**
Model	8063-7000	8063-7300	8063-7400
Description	Naturally Aspirated	Turbocharged	Turbocharged-Aftercooled
Number of Cylinders	6	6	6
Bore and Stroke	4.84 in × 5 in (123 mm × 127 mm)	4.84 in × 5 in (123 mm × 127 mm)	4.84 in × 5 in (123 mm × 127 mm)
Displacement	552 cu in (9.05 liters)	552 cu in (9.05 liters)	552 cu in (9.05 liters)
Rated Gross Power:			
SAE: 77°F (25°C) and 29.31 in Hg (99 kPa) Bar. (Dry)	288 BHP (215 kW) @ 2100 RPM	—	—
85°F (29.4°C) and 29.00 in Hg (98.19 kPa) Barometer (Dry)	—	330 BHP (246 kW) @ 2100 RPM	345 BHP (257 kW) @ 2100 RPM
Continuous Gross Power: 85°F (29.4°C) and 29.00 in Hg (98.19 kPa) Barometer (Dry)	225 BHP (168 kW) @ 1800 RPM	—	—
Torque:			
SAE: 77°F (25°C) and 29.31 in Hg (99 kPa) Bar. (Dry)	777 lb ft (1054 N•m) @ 1600 RPM	—	—
85°F (29.4°C) and 29.00 in Hg (98.19 kPa) Barometer (Dry)	—	953 lb ft (1292 N•m) @ 1300 RPM	953 lb ft (1292 N•m) @ 1400 RPM
Compression Ratio	19 to 1	17 to 1	17 to 1
Approximate Dimensions:			
Length	41 in (1041 mm)	41 in (1041 mm)	41 in (1041 mm)
Width	39 in (991 mm)	39 in (991 mm)	39 in (991 mm)
Height	47 in (1194 mm)	52 in (1321 mm)	52 in (1321 mm)
Net Weight (Dry)	1960 lbs (889 kg)	2005 lbs (909 kg)	2025 lbs (919 kg)

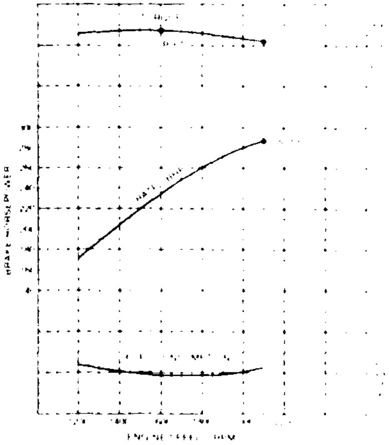
For complete dimensional information, refer to installation drawing 2SA393 for Model 8063-7000, 2SA413 for Model 8063-7300, 2SA394 for Model 8083-7000, and

Rating Explanation

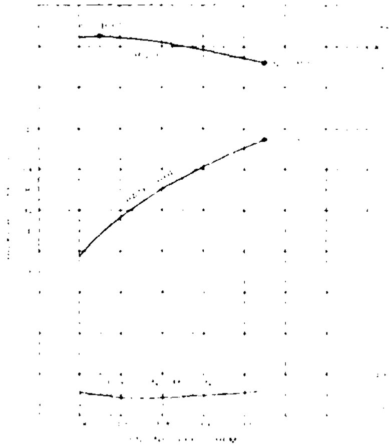
RATED BHP is the power rating for variable speed and load applications where full power is required intermittently. FUEL CONSUMPTION not include power requirements for accessory and standard equipment. For complete engine specifications for your particular requiremer

†Rating conditions of SAE 77°F (25°C) and 29.31 in Hg (99 kPa) Barometer (Dry) *Rating conditions of 85°F (29.4°C) and 29.00 in Hg (98.19 kPa) Barometer (Dry

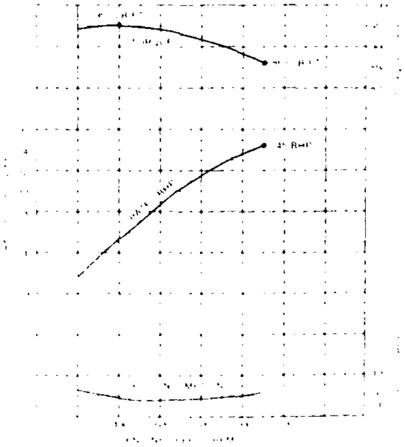
BASIC ENGINE PERFORMANCE MODEL 6V-92 WITH 9285 INJECTORS†



BASIC ENGINE PERFORMANCE MODEL 6V-92T WITH 9B90 INJECTORS*



BASIC ENGINE PERFORMANCE MODEL 6V-92TA WITH 9B90 INJECTORS*



specifications

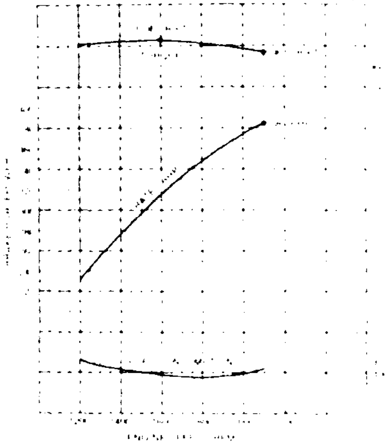
8V-92 9285 Injectors	**8V-92T 9A90 Injectors**	**8V-92TA 9A90 Injectors**
8083-7000	8083-7300	8083-7400
Naturally Aspirated	Turbocharged	Turbocharged-Aftercooled
8	8	8
4.84 in × 5 in (123 mm × 127 mm)	4.84 in × 5 in (123 mm × 127 mm)	4.84 in × 5 in (123 mm × 127 mm)
736 cu in (12.07 liters)	736 cu in (12.07 liters)	736 cu in (12.07 liters)
384 BHP (286 kW) @ 2100 RPM	—	—
—	435 BHP (325 kW) @ 2100 RPM	450 BHP (336 kW) @ 2100 RPM
300 BHP (224 kW) @ 1800 RPM	—	—
1036 lb ft (1405 N•m) @ 1600 RPM	—	—
—	1252 lb ft (1697 N•m) @ 1200 RPM	1257 lb ft (1704 N•m) @ 1400 RPM
19 to 1	17 to 1	17 to 1
48 in (1219 mm)	48 in (1219 mm)	48 in (1219 mm)
39 in (991 mm)	39 in (991 mm)	39 in (991 mm)
51 in (1295 mm)	52 in (1321 mm)	52 in (1321 mm)
2345 lbs (1064 kg)	2395 lbs (1086 kg)	2415 lbs (1095 kg)

and A414 for Model 8083-7300.

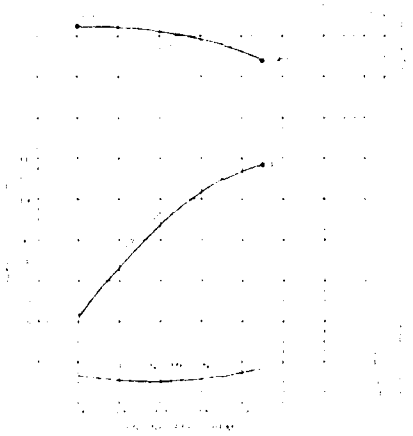
performance

ION CURVE shows fuel used in pounds per brake horsepower hour THIS RATING does
ments, see your distributor or authorized Detroit Diesel Allison representative
(Dry).

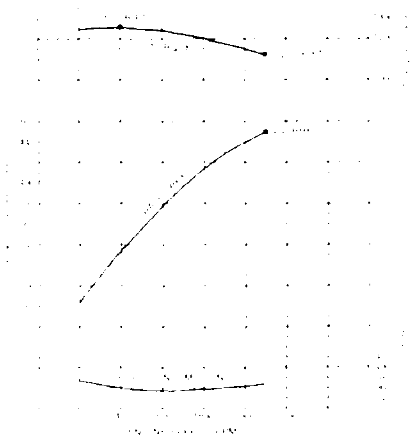
BASIC ENGINE PERFORMANCE
MODEL 8V-92 WITH 9285 INJECTORS†



BASIC ENGINE PERFORMANCE
MODEL 8V-92T WITH 9A90 INJECTORS*



BASIC ENGINE PERFORMANCE
MODEL 8V-92TA WITH 9A90 INJECTORS*



standard equipment

Aftercooler

Air Inlet Housing

Alternator—12 volt, 65 amps, 6V-92, 6V-92T, and 6V-92TA only; 24 volt, 65 amps 8V-92, 8V-92T, and 8V-92TA only

Crankshaft Pulley

Engine Mounts

Exhaust Manifold

Fan—28 in. 6 blades, right-hand, suction, 6V-92 only; 32 in. 8 blades, right-hand, suction, 5V-92T and 6V-92TA; 34 in. 8 blades, right-hand, suction, 8V-92, 8V-92T, and 8V-92TA

Flywheel—SAE #1

Flywheel Housing—SAE #1

Fuel Filters—Spin-on

Governor—Limiting speed

Injectors—Cam operated, unit type, clean tip

Instruments—Water temperature, oil pressure, ammeter, and starter switch, 8V-92 and 8V-92T only

Lube Oil Cooler

Lube Oil Filter—Full flow, spin-on

Oil Pan—25° rear down or 15° front down inclination angle, rear sump, 6V-92, 6V-92T, and 6V-92TA only; 17° inclination angle, rear sump, 8V-92, 8V-92T, and 8V-92TA only

Starting Motor—12 volt, high output, 6V-92, 6V-92T, and 6V-92TA only; 24 volt, 8V-92, 8V-92T, and 8V-92TA only

Turbocharger—6V-92T, 6V-92TA, 8V-92T, and 8V-92TA only

Vibration Damper—Thick, single, heavy, viscous, 8V-92, 8V-92T, and 8V-92TA only

For a complete listing of standard and optional equipment, consult your authorized Detroit Diesel Allison representative.

Specifications subject to change without notice.

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404 [illegible]

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201 246 5074

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31 10 [illegible]

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Detroit Diesel Allison
Division of General Motors

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3SA154 8-83

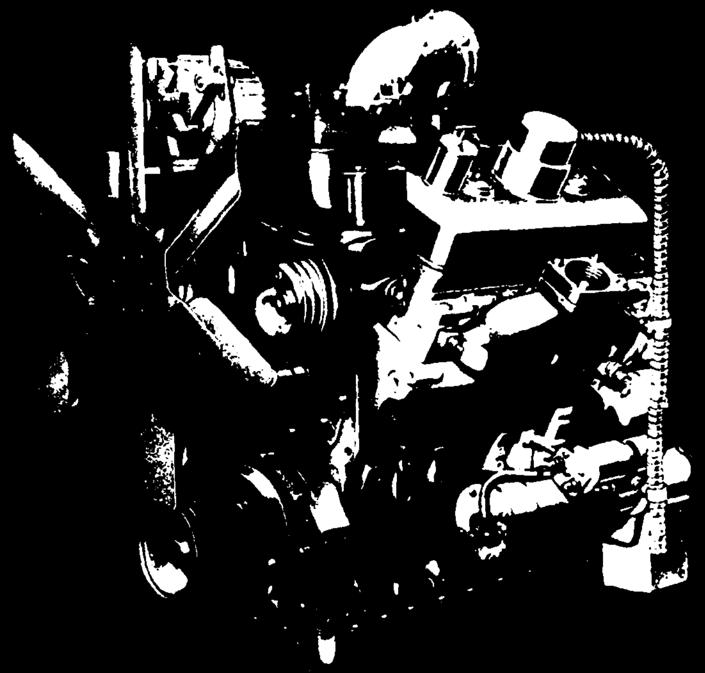
Litho in U.S.A.

Detroit Diesel Engines

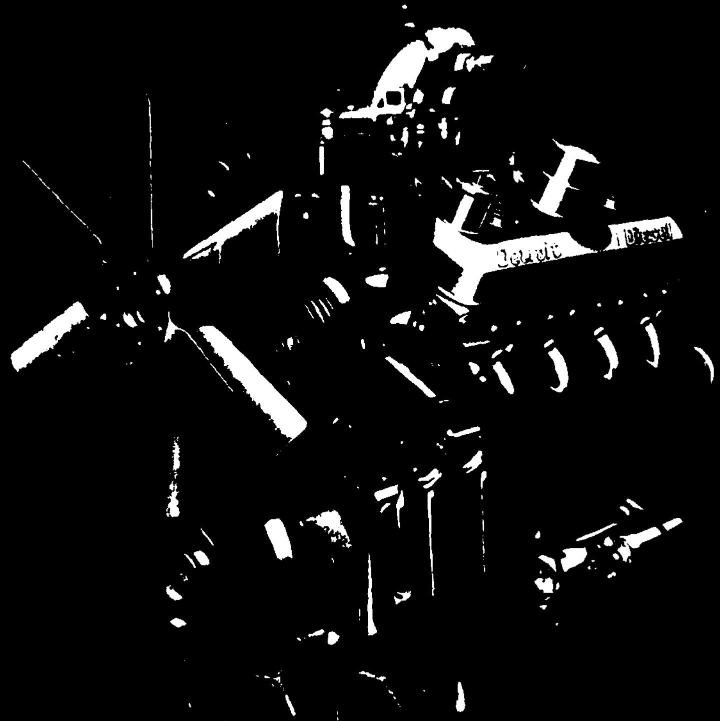
fan-to-flywheel models

POWER PRODUCTS, INC.
90 BAY STATE RD.
WAKEFIELD, MASS. 01880
617-246-1810

6V-71	6V-71T	8V-71	8V-71T
230 hp	277 hp	305 hp	362 hp



Typical 6V-71
Fan-To-Flywheel Model



Typical 8V-71
Fan-To-Flywheel Model

Basic Engine	**6V-71 C65 Injectors**	**6V-71T N75 Injectors**
Model	7063-7000	7063-7300
Description	Naturally Aspirated	Turbocharged
Number of Cylinders	6	6
Bore and Stroke	4.25 in × 5 in (108 mm × 127 mm)	4.25 in × 5 in (108 mm × 127 mm)
Displacement	426 cu in (6.99 liters)	426 cu in (6.99 liters)
Rated Gross Power:		
SAE: 77°F (25°C) and 29.31 in Hg (99 kPa) Barometer (Dry)	230 BHP (172 kW) @ 2100 RPM	—
85°F (29.4°C) and 29.00 in Hg (98.19 kPa) Barometer (Dry)	—	277 BHP (207 kW) @ 2100 RPM
Continuous Gross Power:		
SAE: 77°F (25°C) and 29.31 in Hg (99 kPa) Barometer (Dry)	176 BHP (131 kW) @ 1800 RPM	—
Torque:		
SAE: 77°F (25°C) and 29.31 in Hg (99 kPa) Barometer (Dry)	609 lb ft (826 N•m) @ 1600 RPM	—
85°F (29.4°C) and 29.00 Hg (98.19 kPa) Barometer (Dry)	—	765 lb ft (1037 N•m) @ 1400 RPM
Compression Ratio	18.7 to 1	17 to 1
Approximate Dimensions:		
Length	41 in (1041 mm)	41 in (1041 mm)
Width	39 in (991 mm)	40 in (1016 mm)
Height	48 in (1219 mm)	53 in (1346 mm)
Net Weight (Dry)	2010 lbs (912 kg)	2080 lbs (944 kg)

For complete dimensional information, refer to installation drawing 2SA197 for Model 7063-7000, 2SA429 for Model 7063-7300, 2SA198 for Model 7083-700

Rating Explanation

RATED BHP is the power rating for variable speed and load applications where full power is required intermittently.

FUEL CONSUMPTION CURVE shows fuel used in pounds per brake horsepower hour.

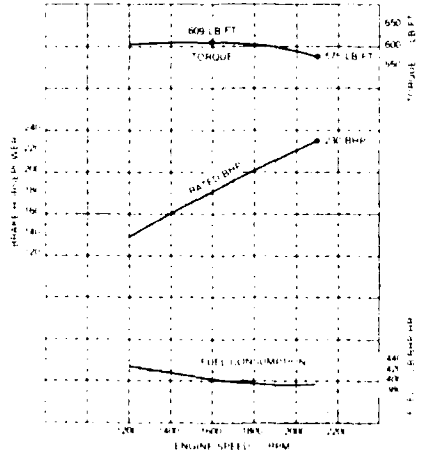
THIS RATING does not include power requirements for accessory and standard equipment.

For complete engine specifications for your particular requirements, see your distributor or authorized Detroit Diesel Allison representative.

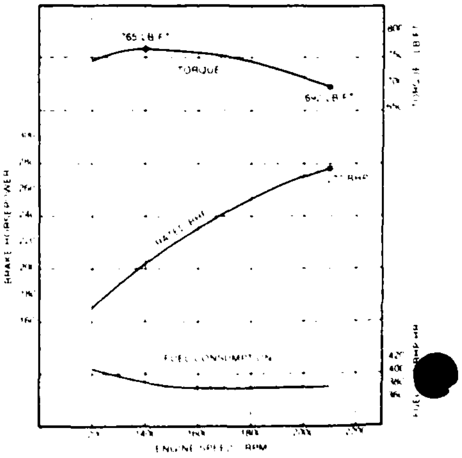
†Rating conditions of SAE: 77°F (25°C) and 29.31 in Hg (99 kPa) Barometer (Dry)

*Rating conditions of 85°F (29.4°C) and 29.00 in Hg (98.19 kPa) Barom-·er (Dry)

BASIC ENGINE PERFORMANCE MODEL 6V-71 WITH C65 INJECTORS†



BASIC ENGINE PERFORMANCE MODEL 6V-71T WITH N75 INJECTORS*



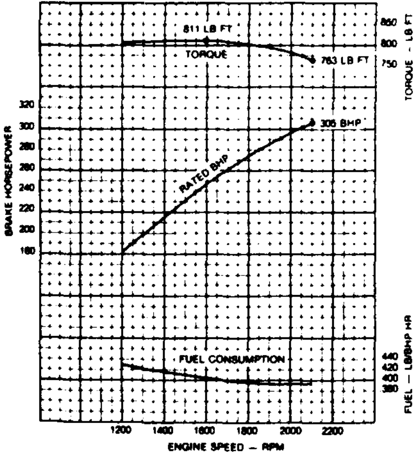
specifications

8V-71 N65 Injectors	8V-71T N75 Injectors
7083-7000	7083-7300
Naturally Aspirated	Turbocharged
8	8
4.25 in × 5 in (108 mm × 127 mm)	4.25 in × 5 in (108 mm × 127 mm)
568 cu in (9.32 liters)	568 cu in (9.32 liters)
305 BHP (228 kW) @ 2100 RPM	—
—	362 BHP (270 kW) @ 2100 RPM
235 BHP (175 kW) @ 1800 RPM	—
811 lb ft (1100 N•m) @ 1600 RPM	—
—	975 lb ft (1322 N•m) @ 1400 RPM
18.7 to 1	17 to 1
47 in (1194 mm)	50 in (1270 mm)
39 in (991 mm)	40 in (1016 mm)
51 in (1295 mm)	53 in (1346 mm)
2310 lbs (1048 kg)	2495 lbs (1132 kg)

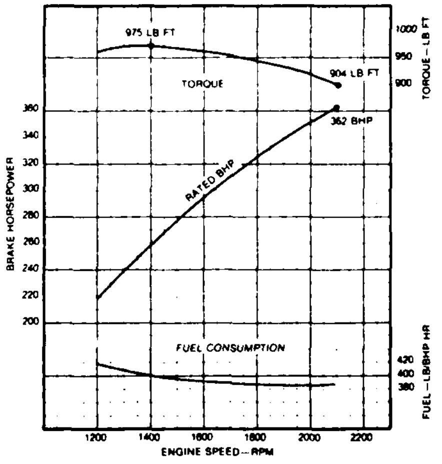
'000, and 2SA381 for Model 7083-7300.

performance

BASIC ENGINE PERFORMANCE
MODEL 8V-71 WITH N65 INJECTORS†



BASIC ENGINE PERFORMANCE
MODEL 8V-71T WITH N75 INJECTORS*



standard equipment

Air Inlet Housing

Alternator—12 volt, 65 amp, 6V-71 and 6V-71T; 24 volt, 65 amp, 8V-71 and 8V-71T

Crankshaft Pulley

Engine Mounts

Exhaust Manifold

Fan—28 in (711 mm), 6 blades, suction, 6V-71 only; 34 in (864 mm), 8 blades, suction, 8V-71 and 8V-71T; fan bracket and pulley assembly only, 6V-71T

Flywheel—SAE #1

Flywheel Housing—SAE #1

Fuel Filters—Spin-on

Governor—Limiting speed, 6V-71, 8V-71, and 8V-71T; variable speed, 6V-71T only

Injectors—Cam operated, unit type, clean tip

Instruments—Ammeter, water temperature and oil pressure gauges, and starter switch, 6V-71, 8V-71, and 8V-71T only

Lube Oil Cooler

Lube Oil Filter—Full-flow, spin-on

Oil Pan—Stamped steel pan for 20° inclination angle, rear sump, 6V-71, 6V-71T, and 8V-71T; stamped steel pan for 17° inclination angle, 8V-71 only

Starting Motor—12 volt, 6V-71 and 6V-71T; 24 volt, 8V-71 and 8V-71T

Turbocharger—6V-71T and 8V-71T only

For a complete listing of standard and optional equipment, consult your authorized Detroit Diesel Allison representative.

Specifications subject to change without notice.

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Detroit Diesel Allison

GM

Detroit Diesel Allison
Division of General Motors

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(313/592-5000)

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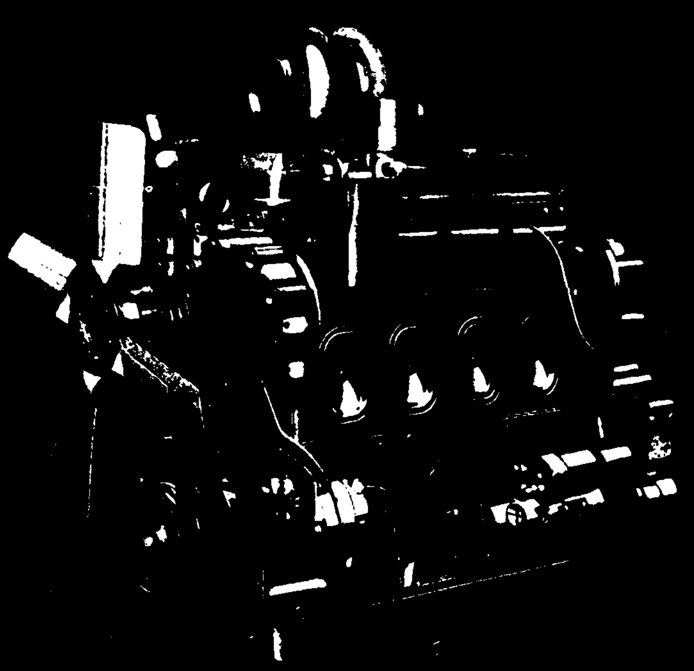
Sao Paulo, Brasil

Detroit Diesel Engines

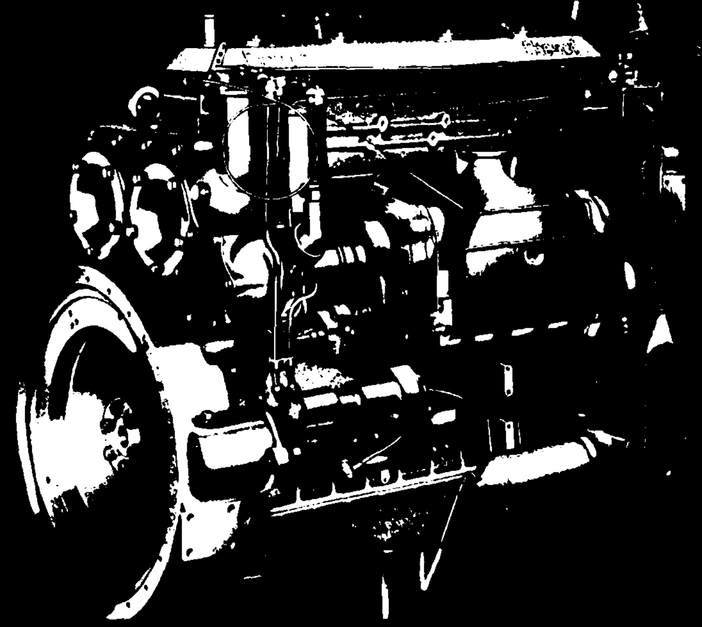
fan-to-flywheel models

POWER PRODUCTS, INC.,
90 BAY STATE RD.,
WAKEFIELD, M[illegible] 1880
617-246-1[illegible]0

4-71	4-71T	6-71	6-71T
155 hp	190 hp	230 hp	285 hp



Typical 4-71T
Fan-to-Flywheel Model



Typical 6-71
Fan-To-Flywheel Model

Basic Engine	**4-71** **N65 Injectors**	**4-71T** **N75 Injectors**
Model	1043-5000, 1043-7000	1043-8300
Number of Cylinders	4	4
Description	Naturally Aspirated	Turbocharged
Bore and Stroke	4.25 in × 5 in (108 mm × 127 mm)	4.25 in × 5 in (108 mm × 127 mm)
Displacement	284 cu in (4.66 liters)	284 cu in (4.66 liters)
Compression Ratio	18.7 to 1	17 to 1
Rated Gross Power:		
SAE: 77°F (25°C) and 29.31 in Hg (99 kPa) Barometer (Dry)	155 BHP (116 kW) @ 2100 RPM	—
85°F (29.4°C) and 29.00 in Hg (98.19 kPa) Barometer (Dry)	—	190 BHP (142 kW) @ 2100 RPM
Continuous Gross Power:		
SAE: 77°F (25°C) and 29.31 in Hg (99 kPa) Barometer (Dry)	118 BHP (88 kW) @ 1800 RPM	—
Torque:		
SAE: 77°F (25°C) and 29.31 in Hg (99 kPa) Barometer (Dry)	407 lb ft (552 N•m) @ 1600 RPM	—
85°F (29.4°C) and 29.00 in Hg (98.19 kPa) Barometer (Dry)	—	525 lb ft (712 N•m) @ 1400 RPM
Approximate Dimensions:		
Length	42 in (1067 mm)	44 in (1118 mm)
Width	29 in (737 mm)	31 in (787 mm)
Height	42 in (1067 mm)	*44 in (1118 mm)*
Net Weight (Dry)	1780 lbs (807 kg)	1830 lbs (830 kg)

For complete dimensional information, refer to installation drawing 2SA78 for Model 1043-5000, 2SA74 for Model 1043-7000, 2SA438 for Model 1043-8300, 2SA72 for

Rating Explanation

RATED BHP is the power rating for variable speed and load applications where full power is required intermittently.

CONTINUOUS BHP is the power rating for applications operating under a constant load and speed for long periods of time.

FUEL CONSUMPTION CURVE shows fuel used in pounds per brake horsepower hour.

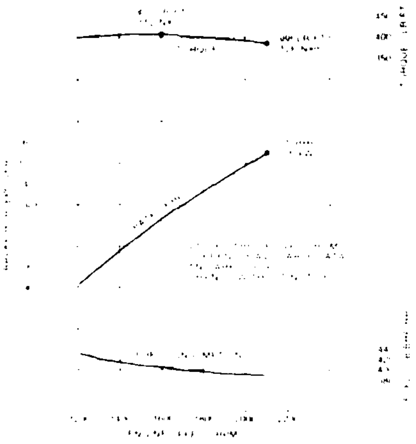
THIS RATING does not include power requirements for accessory and standard equipment.

For complete engine specifications for your particular requirements, see your distributor or authorized Detroit Diesel Allison representative.

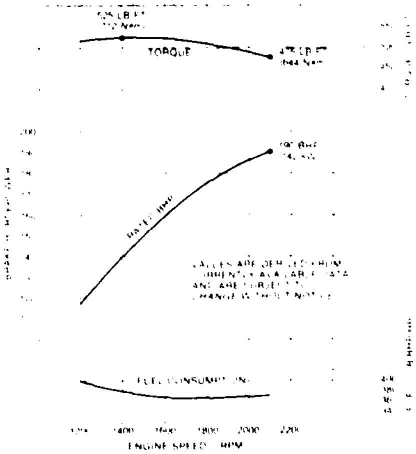
†Rating conditions of SAE: 77°F (25°C) and 29.31 in Hg (99 kPa) Barometer (Dry)

*Rating conditions of 85°F (29.4°C) and 29.00 in Hg (98.19 kPa) Barometer (Dry)

BASIC ENGINE PERFORMANCE MODEL 4-71 WITH N65 INJECTORS†



BASIC ENGINE PERFORMANCE MODEL 4-71T WITH N75 INJECTORS*



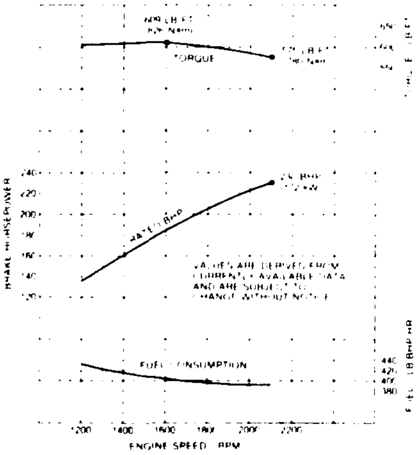
specifications

6-71 N65 Injectors	6-71T N75 Injectors
1063-5000, 1063-7000	1063-8300
6	6
Naturally Aspirated	Turbocharged
4.25 in × 5 in (108 mm × 127 mm)	4.25 in × 5 in (108 mm × 127 mm)
426 cu in (6.99 liters)	426 cu in (6.99 liters)
18.7 to 1	17 to 1
230 BHP (172 kW) @ 2100 RPM	—
—	280 BHP (209 kW) @ 2100 RPM
176 BHP (131 kW) @ 1800 RPM	—
609 lb ft (826 N•m) @ 1600 RPM	—
—	762 lb ft (1033 N•m) @ 1400 RPM
54 in (1372 mm)	56 in (1422 mm)
29 in (737 mm)	32 in (813 mm)
39 in (991 mm)	50 in (1270 mm)
2190 lbs (993 kg)	2240 lbs (1016 kg)

Model 1063-5000, 2SA71 for Model 1063-7000 and 2SA453 for Model 1063-8300.

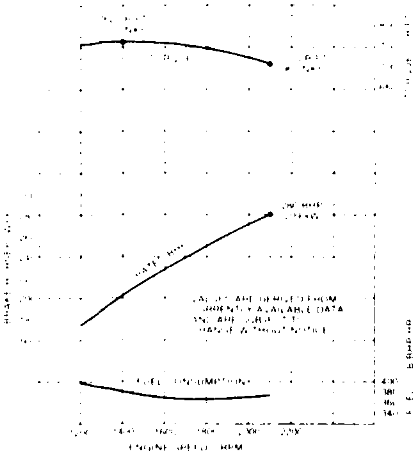
performance

BASIC ENGINE PERFORMANCE
MODEL 6-71 WITH N65 INJECTORS†



VALUES ARE DERIVED FROM CURRENTLY AVAILABLE DATA AND ARE SUBJECT TO CHANGE WITHOUT NOTICE

BASIC ENGINE PERFORMANCE
MODEL 6-71T WITH N75 INJECTORS*



VALUES ARE DERIVED FROM CURRENTLY AVAILABLE DATA AND ARE SUBJECT TO CHANGE WITHOUT NOTICE

standard equipment

Air Inlet Housing

Alternator—12 volt. 42 amp

Crankshaft Pulley

Engine Mounts

Exhaust Manifold

Fan—18 in. 6-blade. suction type. 4-71 only:
26 in. 4-blade. blower type. 4-71T only:
22 in. 6-blade. suction type. 6-71 only:
32 in. 8-blade. blower type. 6-71T only

Flywheel—SAE #3. 4-71T only: SAE #1. 4-71. 6-71. and 6-71T only

Flywheel Housing—SAE #3. 4-71T only: SAE #1. 4-71. 6-71. and 6-71T only

Fuel Filters—Spin-on

Governor—Variable speed. with throttle controls

Injectors—Cam operated. unit type. clean tip

Instruments—Ammeter. oil pressure and water temperature gauges. and starter switch. 4-71. 4-71T. and 6-71 only

Lube Oil Cooler

Lube Oil Filter—Full flow

Oil Pan—Cast iron pan for 16° inclination angle. 4-71 only: stamped steel pan for 20° inclination angle. 4-71T and 6-71 only: cast iron pan for 30° rear down or 28° front down inclination angle. 6-71T only

Shutdown Controls—Manual shutdown with 50 in (1270 mm) cable

Starting Motor—12 volt

Turbocharger—4-71T and 6-71T only

Vibration Damper—Single. heavy. viscous

For a complete listing of standard and optional equipment, consult your authorized Detroit Diesel Allison representative.

Information and specifications subject to change without notice or *obligation.*

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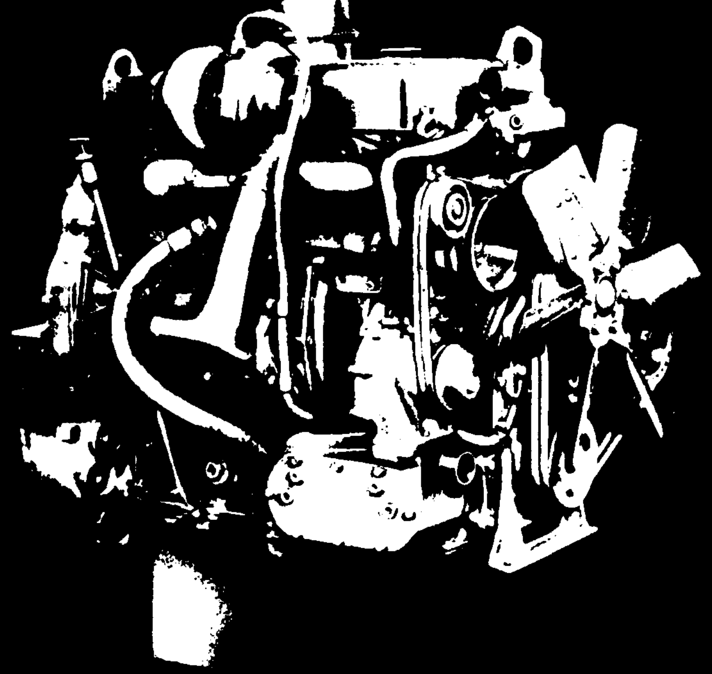
Litho in U.S.A.

Detroit Diesel Engines

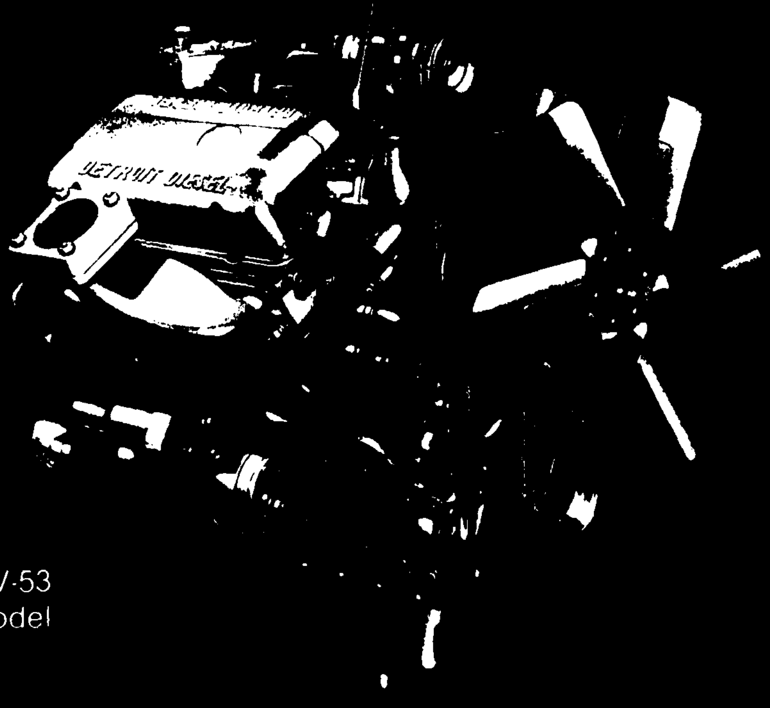
fan-to-flywheel models

[illegible] PRODUCTS, [illegible]
[illegible]
WAKEFIELD, MASS. 01880
617-246-1810

3-53	3-53T	4-53	4-53T	6V-53	6V-53T
98 hp	131 hp	136 hp	175 hp	210 hp	235 hp



Typical 4-53T
Fan-To-Flywheel Model



Typical 6V-53
Fan-To-Flywheel Model

Basic Engine	**3-53 N50 Injectors**	**3-53T N65 Injectors**	**4-53 N50 Injectors**
Model	5033-7000	5033-8300	5043-7000
Number of Cylinders	3	3	4
Bore and Stroke	3.875 in × 4.5 in (98 mm × 114 mm)	3.875 in × 4.5 in (98 mm × 114 mm)	3.873 in × 4.5 in (98 mm × 114 mm)
Displacement	159 cu in (2.61 liters)	159 cu in (2.61 liters)	212 cu in (3.48 liters)
Rated Gross Power: 85 °F (29.4 °C) and 29.00 in Hg (98.19 kPa) Barometer (Dry)	98 BHP (73 kW) @ 2800 RPM	131 BHP (98 kW) @ 2500 RPM	136 BHP (101 kW) @ 2800 RPM
Continuous Rating: 85 °F (29.4 °C) and 29.00 in Hg (98.19 kPa) Barometer (Dry)	70 BHP (52 kW) @ 2400 RPM	—	93 BHP (69 kW) @ 2400 RPM
Torque: 85 °F (29.4 °C) and 29.00 in Hg (98.19 kPa) Barometer (Dry)	205 lb ft (278 N•m) @ 1800 RPM	312 lb ft (423 N•m) @ 1600 RPM	282 lb ft (382 N•m) @ 1800 RPM
Compression Ratio	21 to 1	18.7 to 1	21 to 1
Approximate Dimensions:			
Length	33 in (838 mm)	33 in (838 mm)	39 in (991 mm)
Width	27 in (686 mm)	29 in (737 mm)	27 in (686 mm)
Height	35 in (889 mm)	*40 in (1016 mm)*	*37 in (940 mm)*
Approx. Net Weight (Dry)	965 lbs (438 kg)	1000 lbs (454 kg)	1110 lbs (503 kg)

For complete dimensional information, refer to installation drawing 2SA302 for Model 5033-7000, 2SA449 for Model 5033-8300, 2SA262 for Model 5043-7000, 2S

Rating Explanation

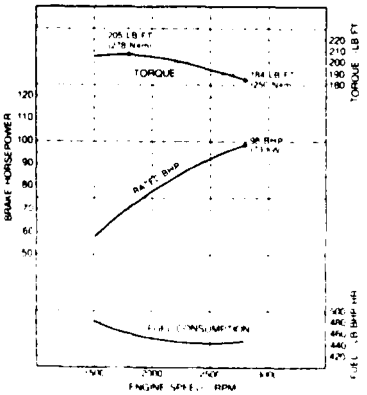
RATED BHP is the power rating for variable speed and load applications where full power is required intermittently.

FUEL CONSUMPTION CURVE shows fuel used in pounds per brake horsepower hour.

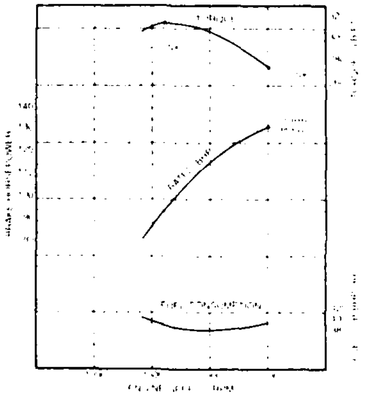
THIS RATING *does not include power requirements for accessory and standard equipment.*

For complete engine specifications for your particular requirements, see your distributor or authorized Detroit Diesel Allison representative.

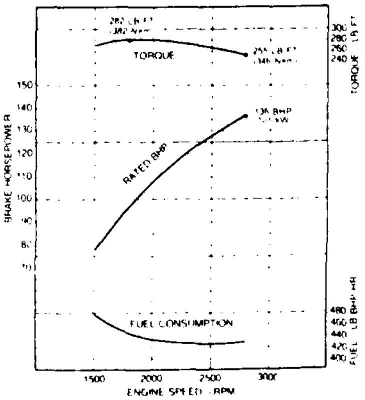
BASIC ENGINE PERFORMANCE MODEL 3-53 WITH N50 INJECTORS*



BASIC ENGINE PERFORMANCE MODEL 3-53T WITH N65 INJECTORS*



BASIC ENGINE PERFORMANCE MODEL 4-53 WITH N50 INJECTORS*



specifications

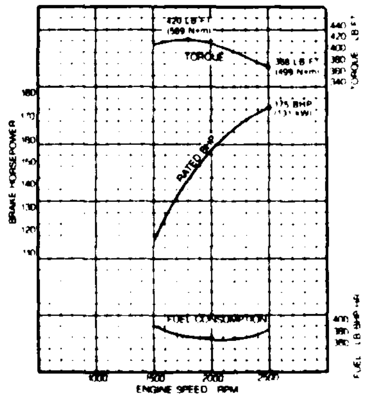
4-53T N65 Injectors	6V-53 N50 Injectors	6V-53T 5A55 Injectors
5043-8301	5063-7000	5063-5300
4	6	6
3.875 in × 4.5 in (98 mm × 114 mm)	3.875 in × 4.5 in (98 mm × 114 mm)	3.875 in × 4.5 in (98 mm × 114 mm)
212 cu in (3.48 liters)	318 cu in (5.22 liters)	318 cu in (5.22 liters)
175 BHP (131 kW) @ 2500 RPM	210 BHP (157 kW) @ 2800 RPM	235 BHP (175 kW) @ 2600 RPM
—	140 BHP (104 kW) @ 2400 RPM	—
420 lb ft (569 N•m) @ 1800 RPM	445 lb ft (603 N•m) @ 1500 RPM	568 lb ft (770 N•m) @ 1800 RPM
18.7 to 1	21 to 1	18.7 to 1
39 in (991 mm) 30 in (762 mm) 39 in (991 mm) 1260 lbs (572 kg)	39 in (991 mm) 40 in (1016 mm) 37 in (940 mm) 1485 lbs (674 kg)	39 in (991 mm) 37 in (940 mm) 41 in (1041 mm) 1695 lbs (769 kg)

2SA444 for Model 5043-8301, 2SA293 for Model 5063-7000 and 2SA448 for Model 5063-5300.

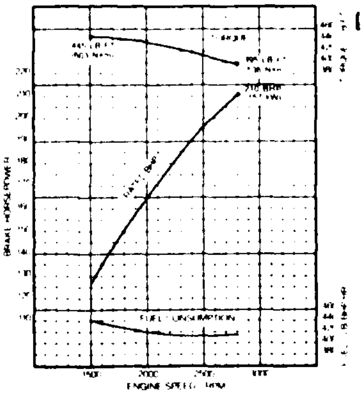
†Rating conditions of SAE: 77 °F (25 °C) and 29.31 in Hg (99 kPa) Barometer (Dry)
*Rating conditions of: 85 °F (29.4 °C) and 29.00 in Hg (98.19 kPa) Barometer (Dry)

performance

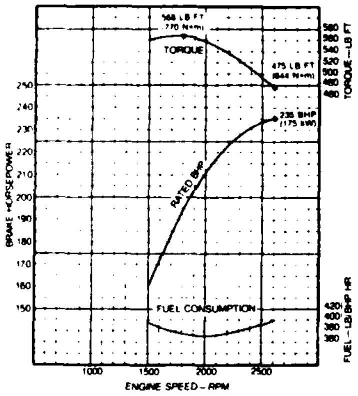
BASIC ENGINE PERFORMANCE
MODEL 4-53T WITH N65 INJECTORS*



BASIC ENGINE PERFORMANCE
MODEL 6V-53 WITH N50 INJECTORS*



BASIC ENGINE PERFORMANCE
MODEL 6V-53T WITH 5A55 INJECTORS*



standard equipment

Air Inlet Housing

Alternator—12 volt, 42 amp

Crankshaft Pulley

Exhaust Manifold

Fan—22 in (559 mm), 5 blades, suction, 3-53, 3-53T, 4-53, and 4-53T; 22 in (559 mm), 6 blades, suction, 6V-53 and 6V-53T

Flywheel—SAE #4, 3-53 and 4-53; SAE #3, 3-53T, 4-53T, and 6V-53; SAE #2, 6V-53T only

Flywheel Housing—SAE #4, 3-53 and 4-53; SAE #3, 3-53T, 4-53T, and 6V-53; SAE #2, 6V-53T only

Fuel Filters

Governor—Variable speed, 3-53, 3-53T, 4-53, 4-53T, and 6V-53; limiting speed, 6V-53T only

Injectors—Cam operated, unit type, clean tip

Instruments—Water temperature gauge, oil pressure gauge, ammeter, and starter switch, 3-53, 4-53, 4-53T, and 6V-53

Lube Oil Cooler

Lube Oil Filter—Full flow; no bypass filter required

Oil Pan—Stamped steel pan for 10° inclination angle, 3-53 only; stamped steel pan for 30° rear or 20° front inclination angle, 3-53T only; stamped steel pan for 20° inclination angle, 4-53 and 4-53T; cast iron pan, 15° inclination angle, 6V-53 only; stamped steel pan for 15° inclination angle, 6V-53T only

Starting Motor—12 volt

Turbocharger—3-53T, 4-53T, and 6V-53T

For a complete listing of standard and optional equipment, consult your authorized Detroit Diesel Allison representative.

Specifications subject to change without notice.

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ZF Steering Gear

2.5. Semi-integral power steering gears

In these power steering gears the mechanical steering gear and the control valve form one unit. The power cylinders are connected to the valve by hose lines. They are generally supported at the axle and the steering arms. Steering gears of this type are installed in vehicles which require higher steering effort due to their higher steering axle load, in which the required hydraulic power exceeds the volume which can be economically housed in the power cylinder of a steering gear of integral design. Installation begins at steering axle loads of approx. 8 tons in vehicles controlled by steering knuckles.
A second possibility for the use of semi-integral power steering gears arises when the push rod is unable to transmit the required steering forces due to its length or offset. Number and size of power cylinders can be selected to provide full hydraulic steering assistance in relation to the max. steering effort which occurs and the required steering speed.

Design

The semi-integral power steering gear comprises a complete manual steering gear, in which the steering effort is transmitted from the input shaft via a ball circuit to the steering nut and from there via a gear system to the sector shaft. The steering nut is moved up and down by the moving thread of the worm and will cause the sector shaft to make a rotary motion. The control valve is located centrally in relation to the input shaft and integrally attached to the steering gear housing. Connections for pressure and return lines, as well as for power cylinders, are on the valve housing. The control valve is mounted on the worm shaft and is moved axially back and forth with the latter. This will displace metering edges in such a manner that the pressure oil can flow from the pump to one end of the power cylinder. When the steering wheel is released, the valve is returned to its neutral position by spring action; the return flow is therefore maintained. This type of steering gear can be optionally provided with a hydraulic steering limiter, as well as with hydraulic reaction.

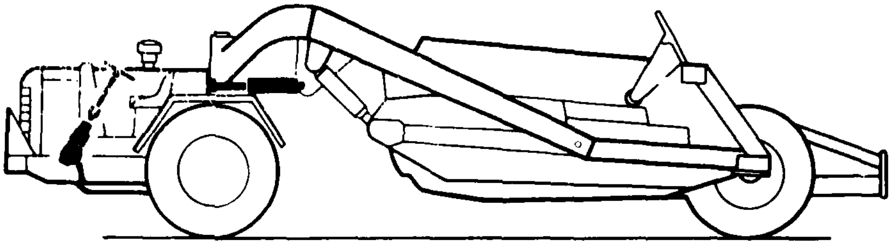


Fig. 29: Scraper loader with semi-integral power steering gear, Type 7402, and power cylinders

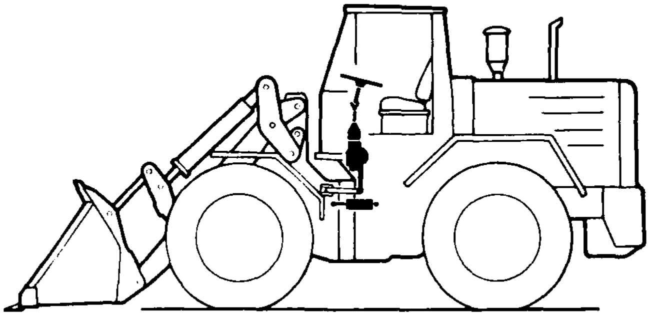


Fig. 30: Articulated shovel loader with semi-integral power steering gear, Type 7401, and power cylinders

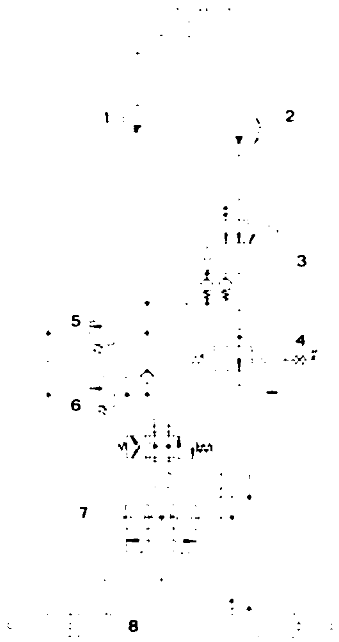
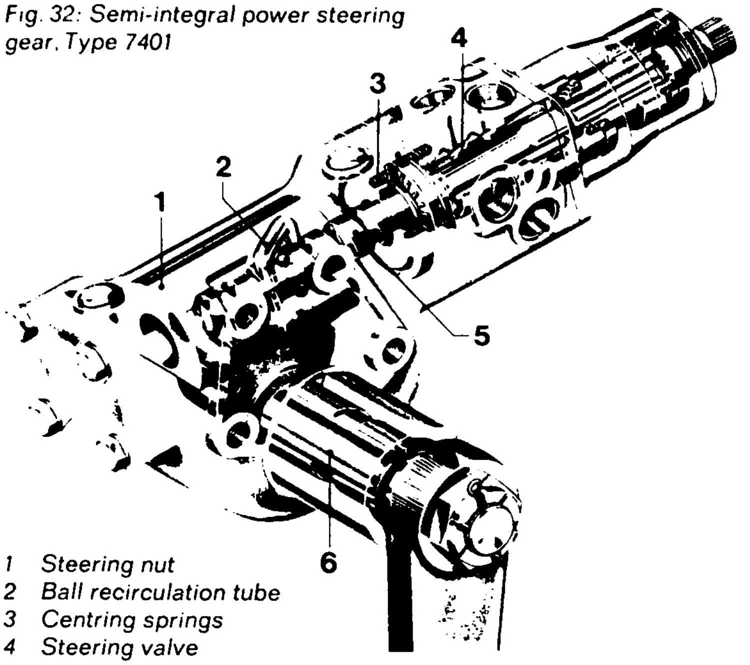


Fig. 31: Hydraulic flow diagram for semi-integral hydraulic power steering gear with remote control valve of the hydraulic steering limiting system, and an emergency steering installation with radial piston pump driven by the road wheels and automatic cut-in valve

1 *Main pump*
2 *Emergency steering pump with flow control*
3 *Automatic stand-by valve*
4 *Flow indicator with control lamp*
5 *Remote control valve for power steering limitation with pressure relief and flow control*
6 *Pressure relief valve*
7 *Semi-integral power steering gear with hydraulic steering limiter for remote control*
8 *Power cylinders*

The valves for limiting hydraulic steering as shown in fig. 33 can be applied for oil flows up to 100 dm³/min. At higher oil volumes in construction machinery, a remote control valve can be used which will start to function when the steering limiting valve responds. The remote control valve will then direct the major portion of the oil flow directly back into the return flow. Pertinent function is shown in fig. 31.

Fig. 32: Semi-integral power steering gear, Type 7401



1 Steering nut
2 Ball recirculation tube
3 Centring springs
4 Steering valve
5 Worm with input shaft
6 Output shaft

Two valve sleeves are incorporated into the housing cover to act as hydraulic steering limiters.
Both spools are fitted by connecting links to a tooth sector, which pivots in the housing cover and is in mesh with a tooth disc fixed to the sector shaft. When the sector shaft is turned, one piston slides upwards and the other downwards. After a certain movement of the valve piston, which can be altered by screwing the valve sleeve in or out, the downwards sliding piston uncovers an oil drain gap in the valve sleeve through which the pressure oil can flow out of the cylinder to the return line.

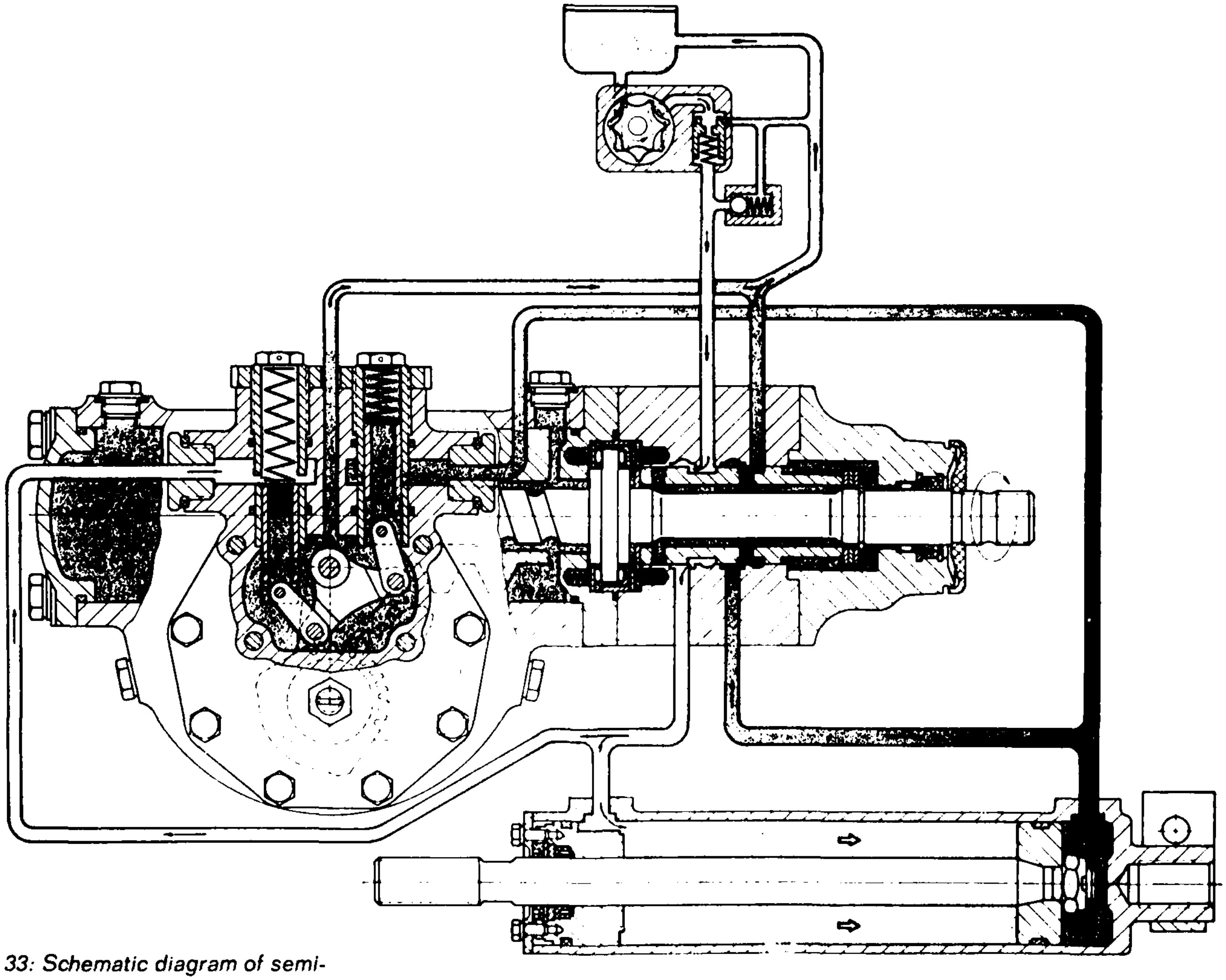
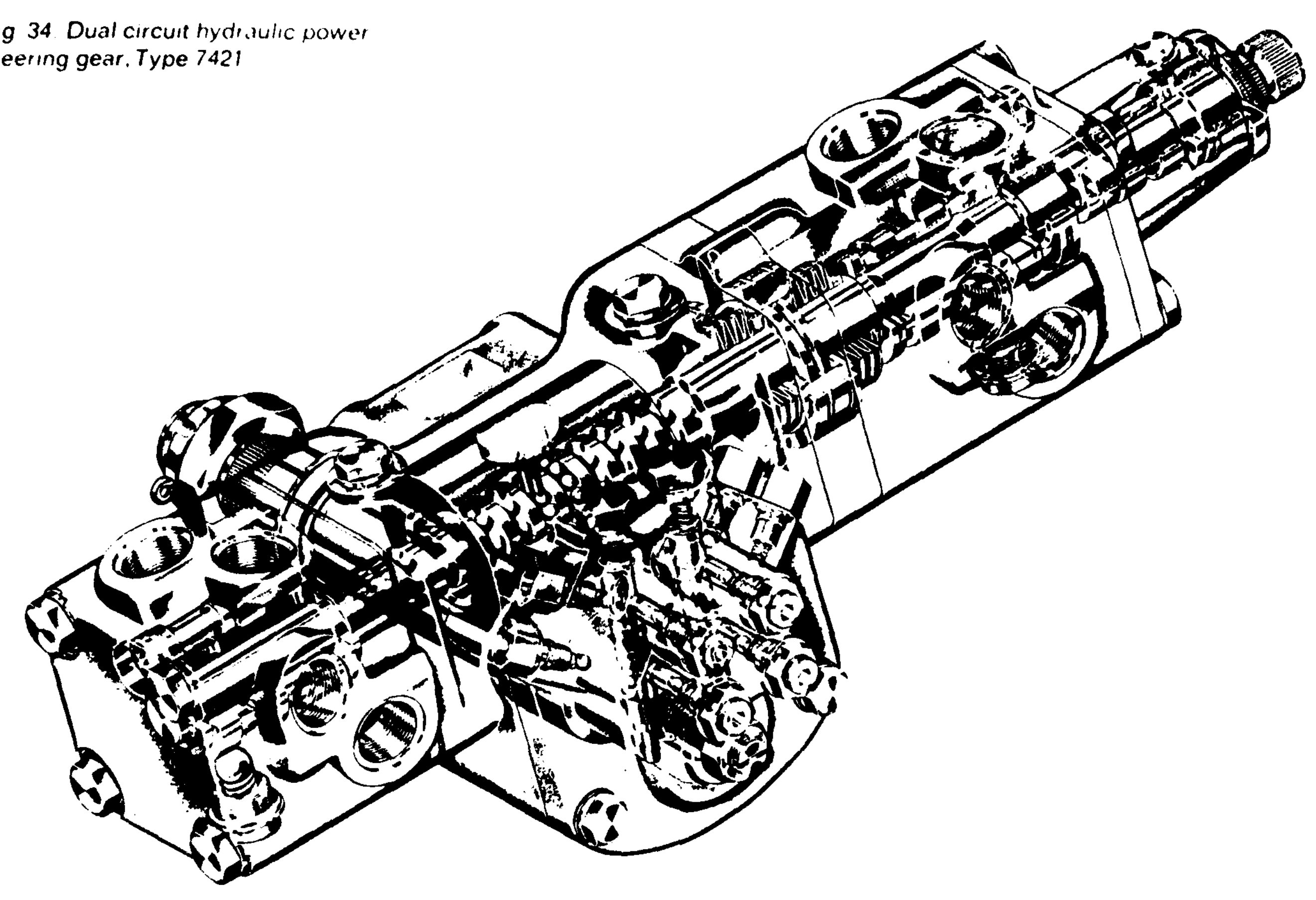


Fig. 33: Schematic diagram of semi-integral hydraulic power steering gear with hydraulic steering limiting system; piston movement to the right just before the stop, steering limiter valves open

D-88

Fig 34 Dual circuit hydraulic power steering gear, Type 7421



2.6. Dual circuit hydraulic power steering gears

Very heavy and special-purpose vehicles with extremely high axle loads cannot usually be steered manually should the hydraulic system fail without exceeding the manual effort limits. For such applications we have developed dual circuit semi-integral steering gear with two independent steering valves which control the oil at high pressure in two entirely separate circuits. Vehicles thus equipped can still be steered by means of one circuit even if oil pressure is totally lost in the other, for instance as a result of a pipe burst. One circuit is normally fed from an engine-driven pump and the other from a transmission-driven pump which operates whenever the vehicle is rolling. However, we have also supplied systems with both circuits fed from an engine-driven pump and an additional circuit consisting of a vehicle-driven pump and cut-in valve.

In order to maintain the driver's "feel" for the road surface through the steering wheel on such heavy vehicles, the dual circuit power steering – for example Type 7421 – can be incorporated into a steering circuit with a degree of hydraulic feedback.

To suit customers' requirements we can also supply the dual circuit power steering system with hydraulic steering limiting.

Pressure in both oil circuits is controlled by remote regulating valves so that a predetermined range of limit movement is provided just before the mechanical steering lock stops are reached. ZF dual circuit power steering systems represent a useful contribution to road safety at reasonable cost.

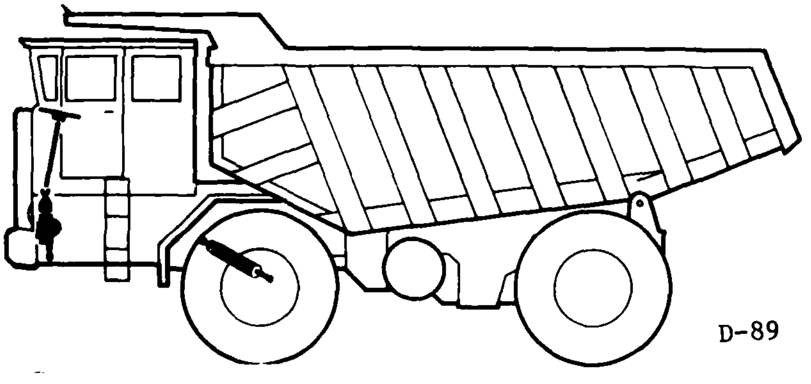


Fig. 35: Four-wheel drive dumper truck with Type 7421 dual circuit hydraulic power steering and one actuating ram for each steering circuit

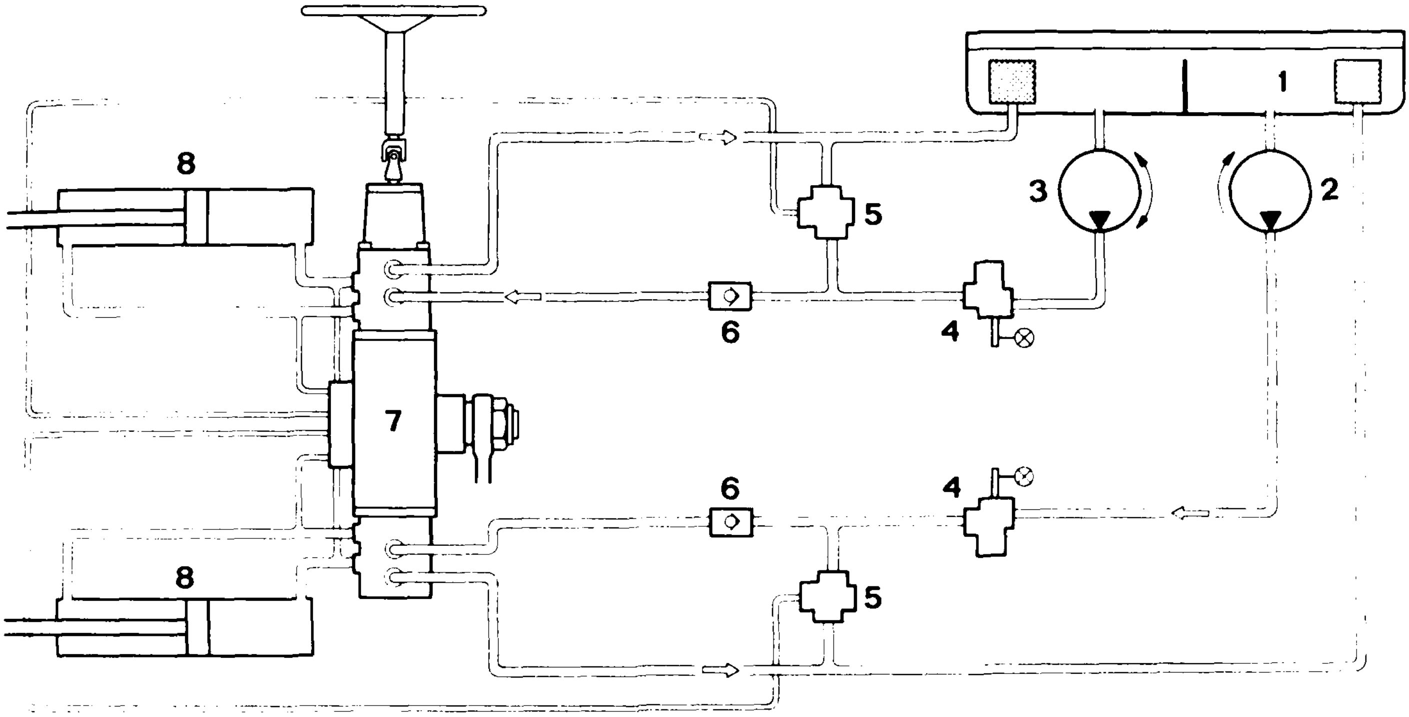


Fig. 36: Schematic representation of a dual circuit steering system

1 *Oil tank with filter*
2 *Engine-driven main pump with flow limiting*
3 *Vehicle-driven radial piston pump with flow limiting*
4 *Flow indicator*
5 *Remote control valve with pressure relief*
6 *Check valve*
7 *Type 7421 dual circuit hydraulic power steering with independent hydraulic steering limiters for each hydraulic circuit*
8 *Power cylinder*

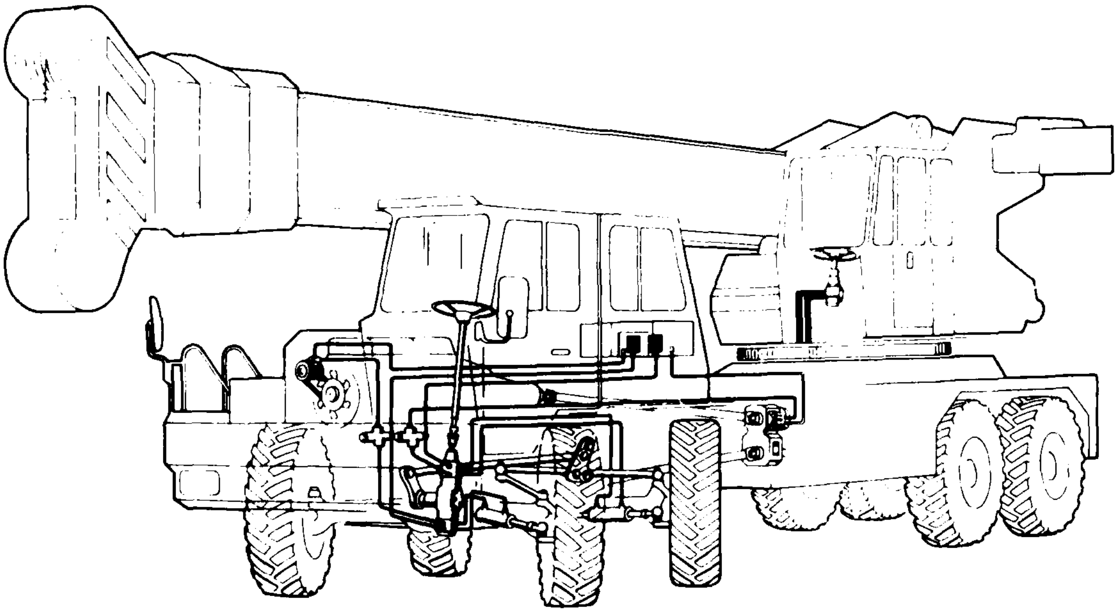


Fig. 37: Specimen installation for Type 7421 dual circuit hydraulic power steering on a truck crane, with Type 7677 engine-driven vane type pump, Type 8607 vehicle-driven radial piston pump and one Type 8465 actuating ram at each steered axle

3. Hydrostatic steering gears
ZF Servostat 2

The ZF Servostat 2 system features hydraulic power assistance and hydrostatic transmission of steering force to the steering wheels of the vehicle. The conventional mechanical linkage is replaced by two columns of oil enclosed in the connecting lines of the system. The vehicle can also be steered without hydraulic power assistance, when it has to be towed away, for example. It is also possible to incorporate our hydrostatic steering systems as a control element in a full power steering layout.

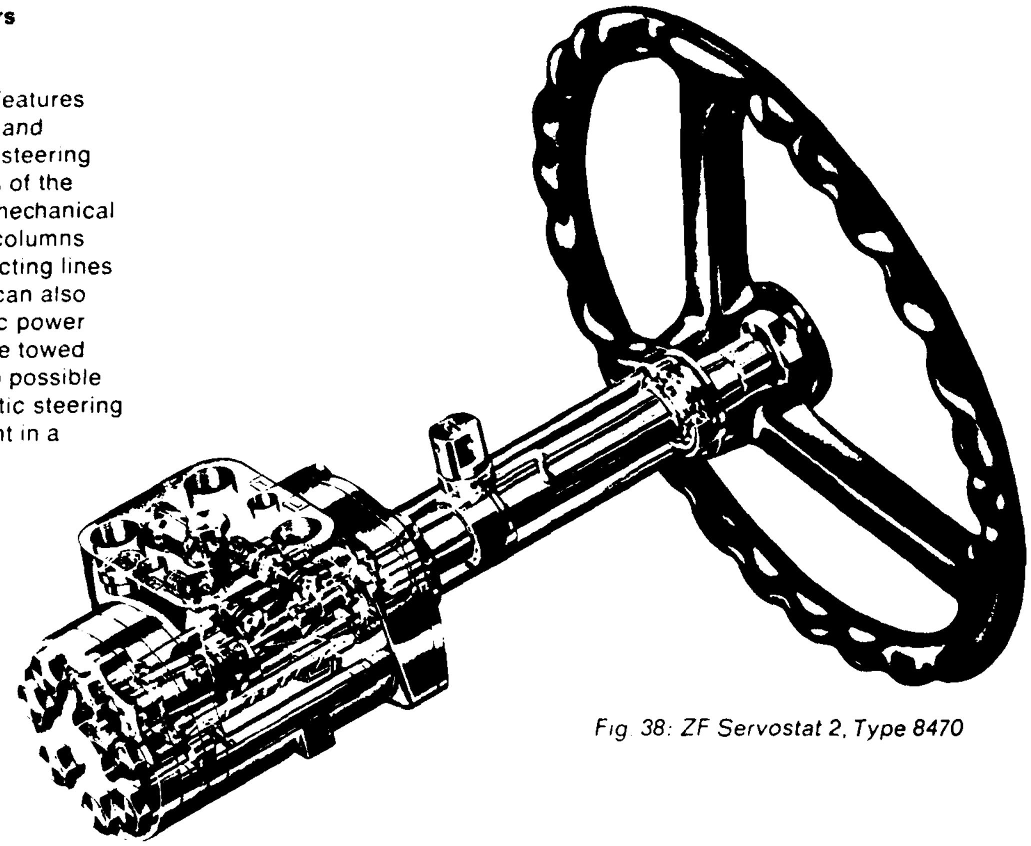


Fig. 38: ZF Servostat 2, Type 8470

The ZF Servostat 2 can be installed in vehicles with a max. design speed of 50 km/h (31 mile/h). It is often chosen for vehicles on which it is difficult to establish a mechanical link between the steering box and the steered road wheels: self-propelled construction machines, stacker trucks, large tractors and harvesters, for example.

Design

The ZF Servostat 2 consists primarily of a metering pump and a control valve. These two assemblies are combined to form a single unit.

The metering pump is a gear-ring pattern rotor pump. The internally toothed stator (2) has seven teeth; in it revolves the externally toothed rotor (3) with six teeth. Oil displacement cavities are formed between the flanks of the teeth as they mesh.

The gear-ring pattern pump requires a rotary distribution control system synchronized with the rotor, since the dividing line between the suction and discharge zones of the pump revolves with the planetary movement of the rotor. Distribution control is by the rotary movement of the spool control valve (12), which is synchronized with the rotor. Depending on turning movement at the steering wheel, the rotor pump meters the volumetric flow of oil from the oil pressure pump (8) and thus synchronizes the angle selected at the steering wheel with the angle adopted by the steered wheels.

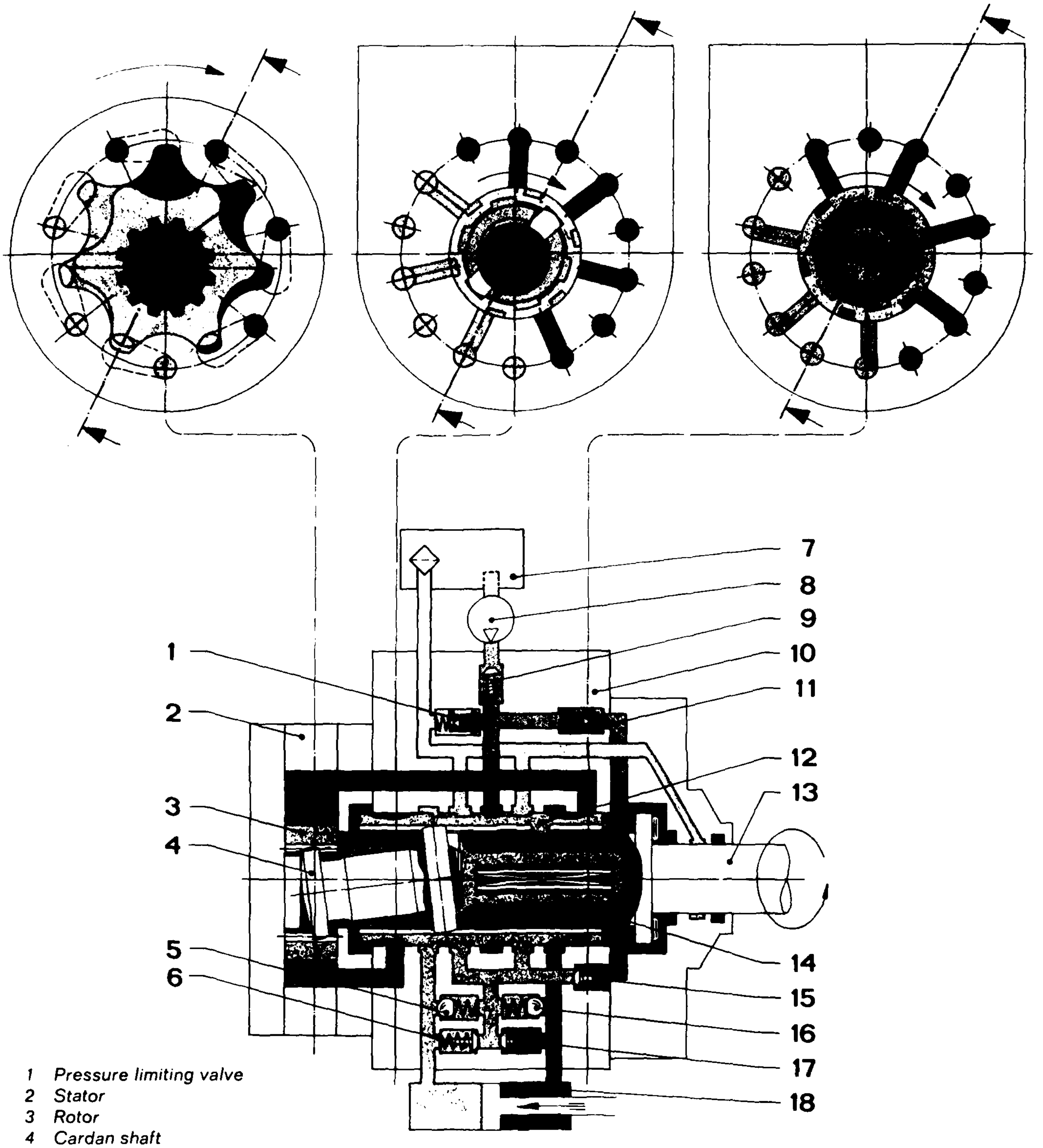
The control valve consists of the steering box housing (10) with valve bore and the spool control valve (12), which can rotate and move axially in the bore. The outer sleeve of the spool valve is provided with radial and axial control grooves, which correspond with channels in the bore wall of the valve. Axial displacement of the spool control valve causes build-up of working pressure and controls the direction of oil flow in accordance with steering wheel movement; rotary movement of the valve controls the distribution action of the metering pump. The spool is coupled to rotor (3) by means of cardan shaft (4) so that no relative rotary movement is possible, and linked at the other end to steering spindle (13) by an adjustable coupling in the form of a steep-pitch thread.

When the steering wheel is turned, relative rotary movement between the steering spindle and the spool control valve displaces the spool control valve axially from its neutral or rest position against the return force exerted by centring springs (14).

The common internal space occupied by the rotor and the control valve is exposed to the discharge pressure from the oil pump. This special design feature reduces gap leakages, prevents hydraulic seizure of the rotor and permits high working pressures to be used.

A series of valves forms an integral part of the ZF Servostat 2 unit in order to satisfy various operating and safety requirements:

- a pressure limiting valve (1), which restricts the discharge pressure from the oil pump (8) to the predetermined system operating pressure;
- two safety valves (5 and 16) to limit peak pressures in the lines to the power cylinder ("closed" version only);
- two replenishing valves (6 and 17), one for each compartment of the power cylinder, to prevent cavitation in the steering system;
- a check valve (9) in the pressure union, approved by the German vehicle testing authorities (TÜV), to prevent air from being drawn in if the pressure line should fracture;
- a non-return valve (11), to prevent automatic return movement of the steered wheels when the control valve is fully open ("closed" version only);
- a bypass valve (15), through which the metering pump can draw up oil from the tank when the steering is operated without hydraulic power assistance.



1	*Pressure limiting valve*
2	*Stator*
3	*Rotor*
4	*Cardan shaft*
5	*Safety valve*
6	*Replenishing valve (cylinder side)*
7	*Oil tank*
8	*Oil pressure pump*
9	*TÜV check valve*
10	*Steering valve*
11	*Non-return valve*
12	*Spool control valve*
13	*Steering spindle*
14	*Spring carrier with centering springs*
15	*Bypass valve (metering pump)*
16	*Safety valve*
17	*Replenishing valve*
18	*Power cylinder*

▨	*Discharge from pressure oil pump*
■	*Metered volumetric flow to power cylinder*
☐	*Return flow*
■	*Trapped oil at non-specific pressure, or changeover phase of distribution control system*

Fig. 39: Operating diagram of ZF Servostat 2 ("closed" version); steering wheel turned counter-clockwise

Two ZF Servostat 2 type series are available (see Figs. 39 and 40). The "open" version (types 8490–8497) permits free return movement of the axle to the straight-ahead position. The "closed" version (types 8470–8477), on the other hand, inhibits return wheel movement. This is designed to prevent shock being transmitted back to the steering wheel, when driving on rough terrain, for instance. On certain types of vehicle, articulated loaders for example, this version is essential to ensure stable steering.

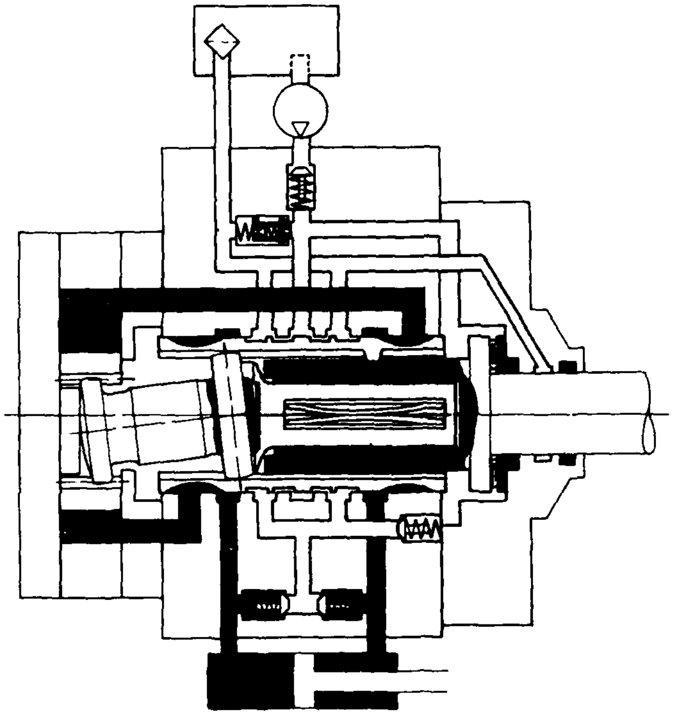


Fig. 40: Diagram of ZF Servostat 2, "open" version, in neutral position

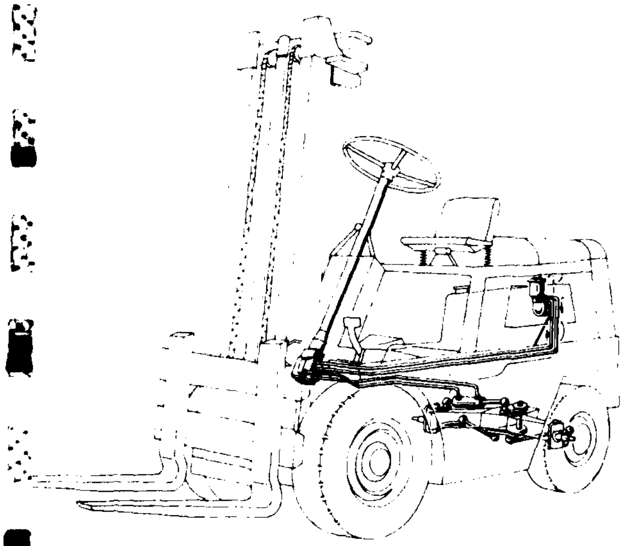


Fig. 41: Fork lift truck with hydrostatic steering, comprising ZF Servostat 2, oil pump (with oil tank attached) and power cylinder

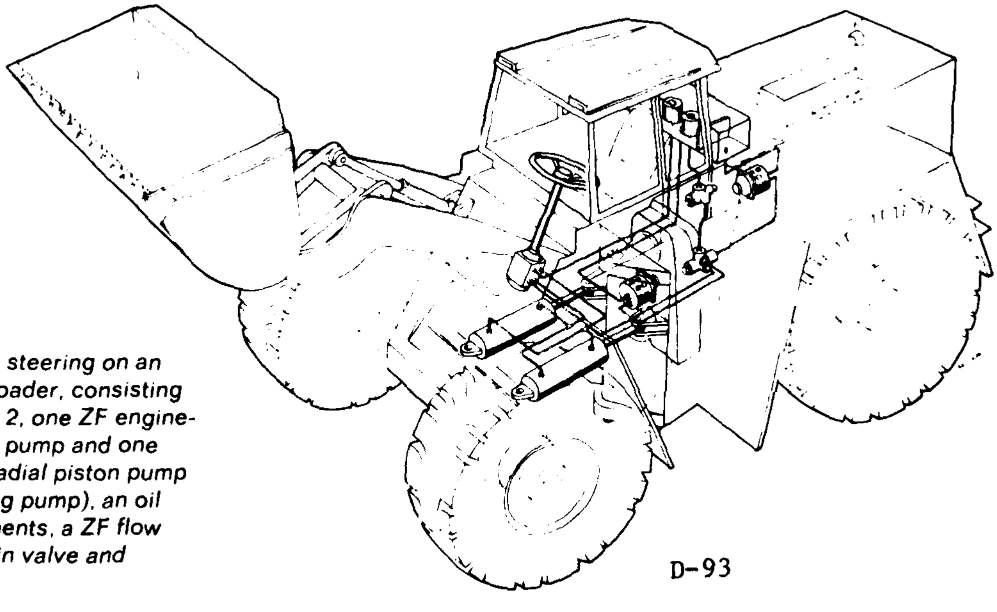
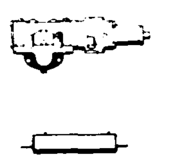
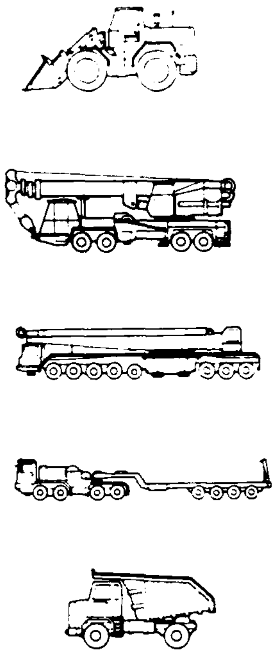
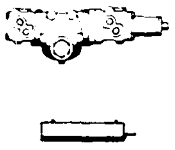


Fig. 42: Hydrostatic steering on an articulated shovel loader, consisting of the ZF Servostat 2, one ZF engine-driven radial piston pump and one ZF vehicle-driven radial piston pump (emergency steering pump), an oil tank with filter elements, a ZF flow indicator, a ZF cut-in valve and ZF power cylinders

ZF Semi-integral Power Steering Gears
for mono- and dual-circuit steering systems

	Type	Ratio	Steering axle load in t*** 20 40 60	Flow rate [dm³/min] (depending on the operating cylinder used, see page 40) 25 50 75 100		
for Mono-circuit steering systems	7421	18.1 : 1 25.6 : 1	55 ⑦	6 – 90 ⑦		
for Dual-circuit steering systems	7421	18.1 : 1 25.6 : 1	> 55	1st circuit 24 – 90 2nd circuit 24 – 90		

Operating cylinder separated from power steering

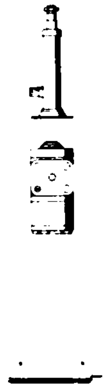
***approx. value

⑦ using 2 valves in parallel, a flow rate up to 180 dm³/min is possible for steering axle loads exceeding 55 t

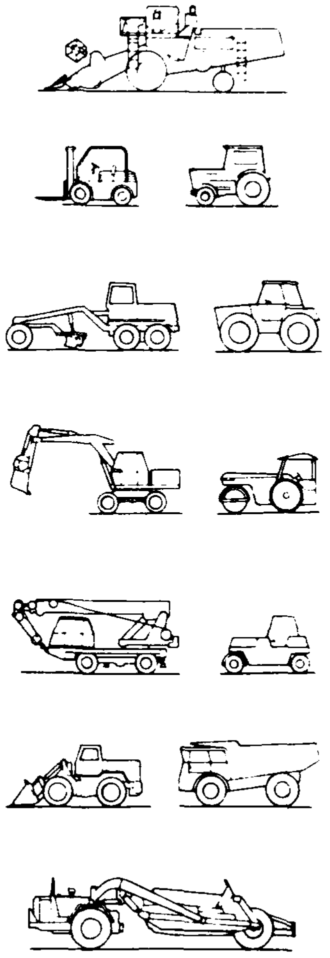
ZF-Servostat 2 · Hydrostatic Steering Gears

Type: closed circuit ⑧	Type: open circuit ⑨	Displacement per steering wheel rotation [cm³]	Steering axle load in t *** (Total weight for vehicles with all-wheel steering)
8470	8490	35 45	1.5
		64	2
8471	8491	72	2.5
		84	3.2
8472	8492	96	4
		120	5
8473	8493	144	6
		167	7
8474	8494	191	8.5
		240	9.5
8475	8495	287	11
		334	13
8476	8496	382	15
		397	16.5
8477	8497	632	18
		798	19.5
8477 with Pilot valve	8497 with Pilot valve	> 1400	22
		> 1700	25

Allocation of 2 operating cylinders required



Operating cylinder separate from the servostat 2



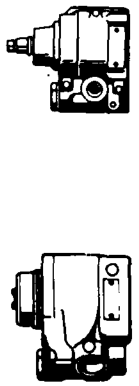
***approx. value

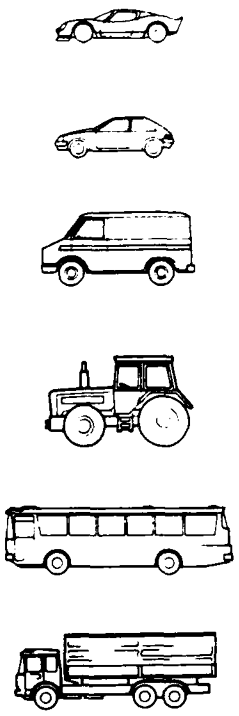
⑧ Neutral cornering behaviour; the steering system cannot be moved through the steered wheels

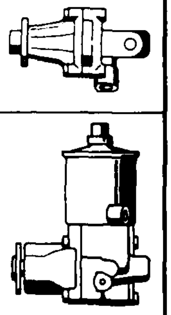
⑨ Positive cornering behaviour, the steering system can be moved through the steered wheels

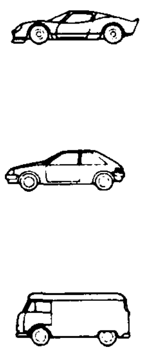
ZF Vane Pumps
for power steering gears

	Type	max. Operating pressure [bar] intermittent	Speed range [1/min] min	Speed range [1/min] max.	theor. Displacement [cm³/rev.]
	7671		500	6 000	8.5 11
	7672		500	6 000	13.5
	7673	100 or 130	500	4 500	16.5
	7674	150 ①	500	4 000	20
	7677		400	3 500	32
new Version	7681	100 130 ①	500	6 000	8.5
	7682		500	6 000	11







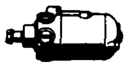
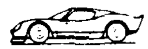
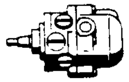
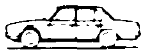
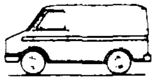
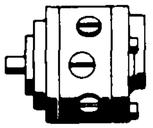
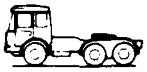
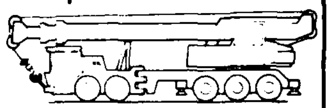


① in development

ZF Radial Piston Pumps
for power steering gears

Type	max. Operating pressure [bar] intermittent	Speed range [1/min] min.	Speed range [1/min] max.	theor. Displacement [cm³/rev.]
8601	200	400	7000	3.5
8604 ①	150	400	5000	10 13
8605	180	250	4500	16
8607				32

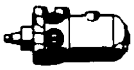
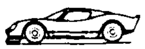
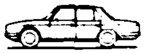
mainly used as emergency steering pump

① in development

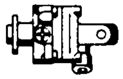
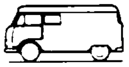
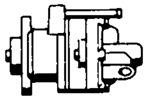
ZF Radial Piston Double Pumps
for power steering gears and other equipment, e.g. brake boosters

Type		max. Operating pressure [bar] intermittent	Speed range [1/min] min.	Speed range [1/min] max.	theor. Displacement [cm³/rev.]
8601	1st circuit	180	400	7000	3
	2nd circuit	200			0.65

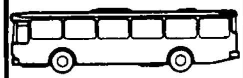
ZF Tandem Pumps

for power steering gears and other equipment, e.g. brake boosters

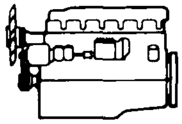
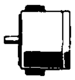
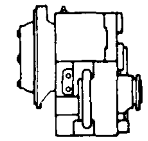
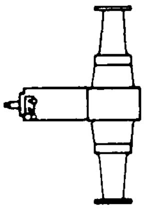
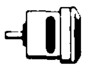
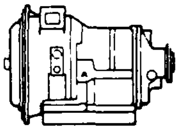
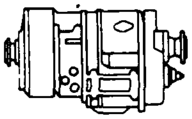
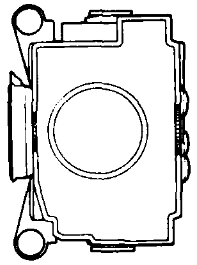
Type	max. Operating pressure [bar] intermittent	Speed range [1/min] min.	max.	theor. Displacement [cm^3/rev.] 2.5 5 7.5 10		
8691	100 130 ①	500	6000	vane pump for power steering gear 8.5		 
	200			radial piston pump for further equipment 0 65		
7600	100 130 ①	500	6000	vane pump for power steering gear 8.5		
	–			vacuum pump for increased braking power		

① in development

ZF Rotor Pumps

Type	max. Operating pressure [bar] intermittent	Speed range [1/min] min.	max.	theor. Displacement [cm^3/rev.] 10 20 30 40		
7633	100	800	4000	11.7		
7634		600	3500	14.1		
7636		500	3000	20.3		
7646		350	2500	32.9		

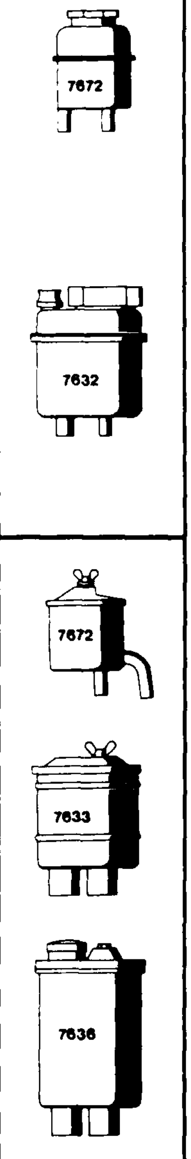
ZF Rotor Low Pressure Pumps

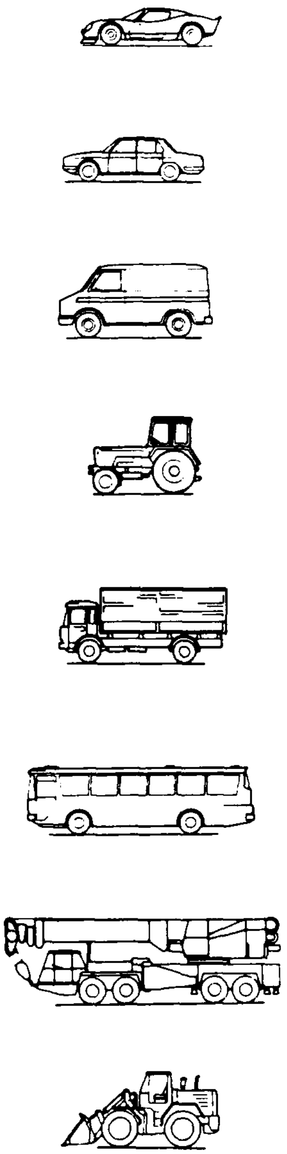
	Type	max. Operating pressure [bar] const.	max. Operating pressure [bar] interm.	Input speed max. 1/min	theor. Displacement [cm^3/rev.] 40 80 120 160		
Rotor pumps	7602	6	10	2 500	0.8 – 4		
	7603				2 – 13		
	7605				2 – 28		
	7606		15		8 – 35		
	7607				10 – 72		
	7616	10			15 – 105		
	7620	20	50	2 500	2 – 5.5		
	7621				5.5 – 6.8		
	7623				8 – 10		
	7630				3 – 8		
	7631				8 – 9.8		
	7632				9.8 – 11.7		
	7644				24 – 27.5		
	7647				36 – 41.5		
Integral gear pumps	7654	20	–	3 700	20 – 25		
	7654				40 – 42		
Rotor pumps / Multi-circuit pumps	7660	6 or 20	50	2 500	8 – 22		
	7661				10 ▨ 15 – 18 ▨ 25		
	7662				15 □ 22 ▨ 40		
	7663				10 – 58		
	7664				25 ▨ 50 □ 55 ▨ 85		
	7666				38 – 120		
	7667				48 – 150		
	7668				65 ▨ 106 – 138 ▨ 150		

□ = available ▨ = on request

ZF Oil Reservoirs with Integrated Filter

	Type	Oil capacity |dm^3| up to mark	
Plastic version	7672	0.4	
	7672 ①	0.5	
	7632	0.7	
Steel sheet version	7672	0.4	
	7632	0.7	also available with reserve capacity for hydrostatic steering gears
	7633	1.0	
	7636	> 1.0	

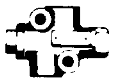
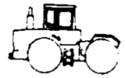
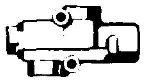
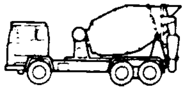
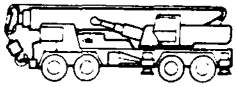
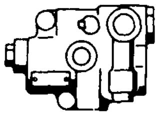
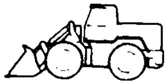
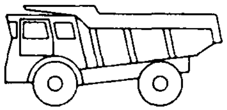




① in development

On request, all reservoirs can be supplied with brackets

ZF Valves

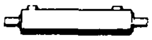
Type		Description	max. Input [dm³/min]	Operating pressure [bar]	Continuous flow rate [dm³/min]		
	Version						
Flow limiting valves	By-pass valve	7720	60		15 – 20		
		7722	200		20 – 140		
Combined pressure and flow limiting valves	By-pass valve	7723 ⑩	60	10 – 180	15 – 20		
		7724	120	50 – 180	25 – 50		
		7725 ⑩	200	30 · 180	20 · 140		
Pressure limiting valves		7753 ⑩	60	10 · 180			
		7755 ⑩	200	30 · 180			
	Screw-in cartridge	8440	50	50 · 180			
		8470	80	50 · 210			
for Vehicles with emergency steering	**Valve block** (cut-in and pressure limiting valve with flow rate indicator)	7760	80 per pump	100 · 210			
	Cut-in valve for the control of 2 oil flows	7734		max. 200	max. flow rate per pump [dm³/min] 80 and 200		
	Flow rate indicator for flow rate control	7780		max. 200	80 and 200		

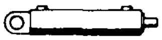
any desired values for operating pressure and continuous flow rate can be set for each valve

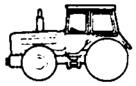
⑩ These valves are also available as remote control versions 7783 and 7785

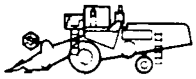
ZF Power Cylinders
standard range

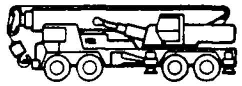
Type	Piston pressure [kN] at max. 180 bar F₁	F₂	Stroke [mm] (The max. pressure depends on the stroke length) 150 200 250 300 350 400 450 500
8343	28.60	21.80	150 – 400
8344	35.30	26.50	150 – 400
8345	42.70	33.90	150 – 400
8346	50.90	39.80	150 – 400
8347	69.20	54.80	150 – 450
8348 ①	102.10	83.80	150 – 450
8349 ①	141.30	118.70	200 – 500

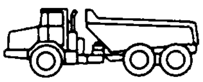












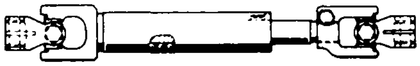
F_1 = Thrust (large piston area) F_2 = Pull (small piston area)

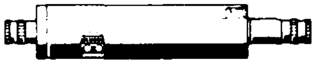
① in development

ZF Relay and Telescopic Shafts

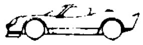
Connecting links between steering wheel and steering gear

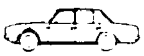
Type		Torque |Nm| (11)	Stroke during operation |mm|	total Stroke e. g. for comm. veh. with tilting cab
ZF Ball type telescopic shafts	7023	50	< 30	> 50
	7026	125	< 30	> 50
	7040	125	< 30	> 50

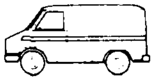


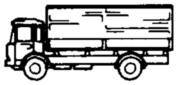


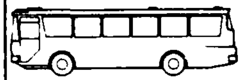
(11) max. permissible for continuous dyn. operation

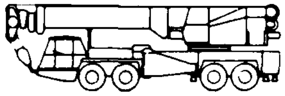








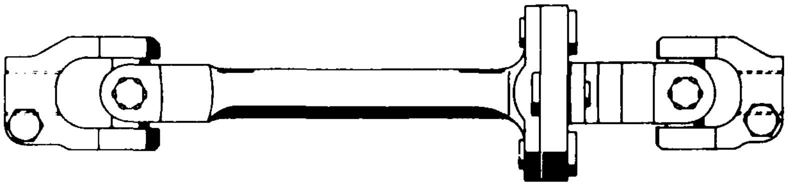




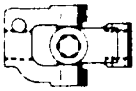
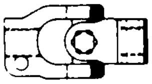
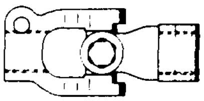
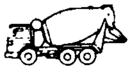
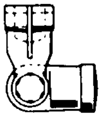
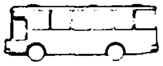
ZF Relay Shafts

Relay shafts (Type 7023 for private cars and Type 7026 for commercial vehicles) of any required dimensions can be supplied upon request. This also applies for rigid shafts and articulations with one or two joints and two-hole or multi-hole flanges or flange type joints

The forks of the relay joints and shafts can be made from either steel or light metal alloy.
Example. Aluminium Relay shaft with damper element Type 7023



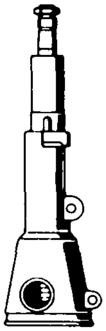
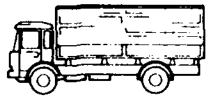
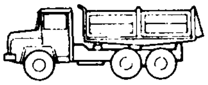
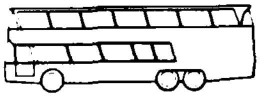
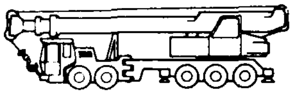
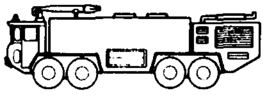
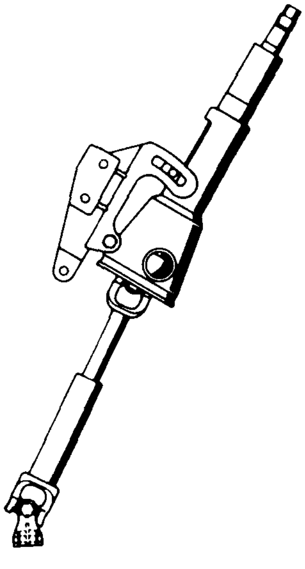
ZF Universal Joints
for application in vehicle and mechanical engineering

	Type	Torque ⑪ [Nm]	Flexure angle of steering column		Fork version		
			during operation	at standstill	Steel	Light metal alloy	
for Private cars and light commercial vehicles	023	50	recommended max. 20° only when one universal joint is used max. 45° with two or more joints	max. 90° possible			
for Medium and heavy duty commercial vehicles	7026	125	recommended max. 20° only when one universal joint is used, max. 45° with two or more joints	max. 90° possible			
	7026	125	for gear shift linkages 90°	90°			

⑪ max. permissible for continuous dynamic operation
max. permissible speed 120/min

ZF Steering Columns for Commercial Vehicles

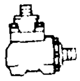
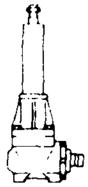
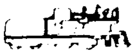
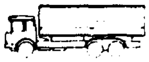
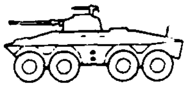
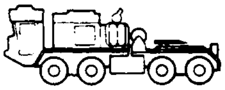
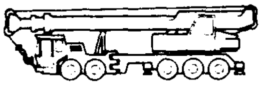
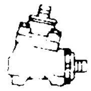
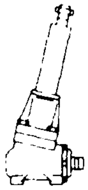
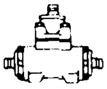
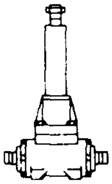
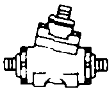
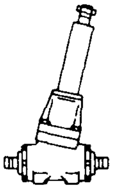
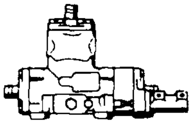
Connecting links between steering wheel and steering gear

	Type	Torque ⑪ [Nm]		
Axially extendable	7360	125		    
Pivotable and axially extendable	7360	125		

⑪ max. permissible for continuous dynamic operation

The dimensions of the steering columns and of the slewing and adjustment ranges are determined following consultation with our engineering department.

ZF Intermediate Steering Gears

	Type	Angle	Torque ⑪ [Nm]	Version Stub shaft	 Jacket tube	
	7860	90°	125			    
	7862	77°	125			
Output from both ends	7861	90°	125			
	7863	77°	125			
	7864	90°	125	 selectable, e. g. for 2 driving positions		

⑪ max. permissible for continuous dynamic operation

Ratio 1 : 1, please contact ZF if other ratios are required

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REPORT DOCUMENTATION PAGE	**READ INSTRUCTIONS BEFORE COMPLETING FORM**
1. REPORT NUMBER 2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Forklift trucks, rough terrain vehicles, off-road vehicles, high speed forklift trucks, high speed off-road vehicles, suspension systems, vehicle handling, drivetrain design, tires.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Objective of this study was to determine the feasibility of increasing the road speed of Army Rough Terrain Forklift Trucks to 45 mph so that they can be self-deployable. The scope of work included the identification of technical obstacles to high speed operation, the definition of system and component modifications that would be required, and the determination of

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Abstract (continued)

commercial availability for the required components.

Although 45 mph operation of these vehicles is feasible, a number of modifications will be required. These include the addition of a suspension system; improvement of weight distribution and the steering system; modification of the drivetrain; and careful attention to the selection and operating conditions for the tires.

Generally, commercial components are available to implement these modifications, although considerable engineering will be required. Tires may place a limitation on time and distance at 45 mph, and it is not clear from available information whether a suitable, commercially available tire exists for the largest machine (10,000 lb. capacity).

END

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