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ENGINEERING DATA ON SELECTED HIGH SPEED PASSENGER TRUCKS

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16. Abstract

The purpose of this Project is to compile a list of high speed truck engineering parameters for characterization in dynamic performance modeling activities. Data tabulations are supplied for trucks from France, Germany, Italy, England, Japan, U.S.S.R., Canada and The United States.

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PREFACE

During the conduct of the program, significant contributions were made by members of the Budd Staff with particular recognition to Mr. Philip Strong.

Acknowledgement is also given to Frank P. DiMasi, Raymond Ehrenbeck, and Herbert Weinstock of TSC for their help in the program.

The Budd Company gratefully acknowledges the following publications for granting permission to reproduce selected pages contained in their magazine articles: Chemins De Fer, French Railway Techniques, Rail Engineering International, and Railway Gazette International. The Budd Company also acknowledges other sources which were made available to them.

METRIC CONVERSION FACTORS

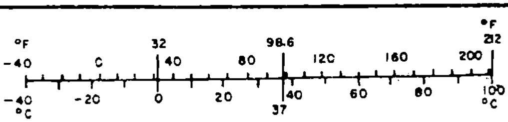
Approximate Conversions to Metric Measures

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

Symbol
mm
cm
m
m
km
cm^2
m^2
km^2
ha
g
kg
t
ml
l
l
l
m^3
m^3
°C

Approximate Conversions from Metric Measures

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



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1. INTRODUCTION

1.1 Background

TSC is supporting the Federal Railroad Administration's improved passenger service program by providing engineering data to support the development of truck design specifications for use in high speed passenger service. A part of this includes analysis of the sensitivity of vehicle performance characteristics to vehicle and truck configurations. Accordingly, TSC is collecting data and analytic tools to conduct a review of the relationship between vehicle and truck configurations, track geometry variations and performance characteristics such as ride vibration and ranges of safe operation speeds.

The truck configuration and its associated compliance, damping and sprung/unsprung mass characteristics represent a major influence of vehicle stability and are important to the truck optimization process. To date, however, there has been no systematic effort to catalog this data in order to characterize the diverse population of current and proposed truck designs. The purpose of this project has been to assemble such data to characterize passenger truck configurations for use in parametric studies to assess the influence of truck (and vehicle) parameters on performance characteristics such as vehicle stable performance and ride vibration.

The Budd Company, a major developer of rail vehicle/truck systems, has collected a library of data on many truck designs from: internal development projects; published technical literature; and personal contact with international representatives. The object of this contract was to provide the required catalog of passenger truck configuration data for powered and non powered trucks by taking maximum advantage of existing raw data gathered by The Budd Company. The data presented in this report is limited in scope in that it is information which was available and retrievable from The Budd Company files only.

1.2 Objectives

The objectives of this contract are as follows:

- A Compilation of truck design configurations in current use or proposed for use in improved intercity rail passenger service.

- A tabulation of the engineering parameters necessary for modeling of the dynamic performance of a rail car equipped with these trucks, obtainable from current data.

- A description of car body types in current use or proposed for U.S. passenger service.
- Tabulation of the mass and stiffness properties of the above car bodies.

1.3 Plan

The plan was divided into the following parts:

(A) Literature search for passenger trucks

(B) Truck Description and Illustration

(C) Truck Data Tabulation

(D) Car Data Collection

1.3.1 Literature Search for Passenger Trucks

An extensive search was conducted in the data bank and engineering files of the Budd Technical Center as well as collaboration with other Budd staff members to develop as complete a list of passenger trucks which are in use or proposed for use in U.S. rail passenger service as possible.

When it became apparent that complete physical descriptions could be provided for only a few of the passenger trucks, the Technical Monitor designated certain high speed trucks as priority trucks for which complete descriptions would be provided. The list of passenger trucks was then condensed to include only selected high speed trucks for data collection purposes. A high speed truck is considered to be designed for speeds of 125 mph (200 kmh) or greater.

1.3.2 Truck Data Description and Illustration

A description and a spring-mass-damper sketch of each truck was made to aid in clarifying each high speed truck. The description includes information on the primary and secondary suspension systems and a brief history of the truck whenever available.

1.3.3 Truck Data Tabulation

This section includes a major portion of the work performed on this contract; i.e., analysis of the information available to obtain detailed dynamic data. Several engineering articles for each high speed truck were studied before attempting a data tabulation. Several iterations were made to achieve an appropriate engineering format. Tables of truck information were primarily based on the raw data and engineering estimates were made where data was incomplete or unavailable. These estimates are denoted by an asterisk in the table. Estimates were made based on The Budd Company's experience in the railcar industry and should be treated as engineering approximations.

1.3.4 Car Data Collection

For each high speed truck tabulated car data is provided to include the significant parameters for dynamic modeling purposes.

2. TRUCK LIST

2.1 Passenger Truck List

This list presents the passenger trucks which are based on the Budd Company's available data and literature. Trucks from France, Germany, Japan, Switzerland, Italy, Sweden, England, Canada, Australia, U.S.S.R., and the United States have been included.

The list indicates the truck or vehicle designation, the truck builder, whether it is powered or unpowered, if some data is available or not, the system the truck is used on, and the application, transit, mainline, or commuter. On the truck list under the category powered, if both yes and no appears, this indicates that at least one truck is powered on the vehicle, and that one is unpowered.

PASSENGER TRUCK LIST

COUNTRY	TRUCK OR VEHICLE DESIGNATION	TRUCK BUILDER	POWERED	SOME DATA AVAILABLE	SYSTEM USED ON	APPLICATION		
						Transit	Mainline	Commuter
FRANCE	Y20	SNCF	No	Yes	Mistral Sud Express		X	
					Paris-Nice Run			
	Y20D	"	No		Car A9 Mistral			
	Y22	"	No					
	Y24	"	No	Yes	Paris-Hendays Sud Express		X	
	Y24A1	"	No		TEE Paris-Brussels Amster-			
	Y24C	"	No		dam CAPITOLE Paris-Tonlouse			
	Y26	"	No		New carriages for Mistral		X	
					SNCF Rest. Cars Paris-Ruhr			
	Y26C	"	No					
	Y26P	"	No	Yes	Rest. Cars of Mistral		X	
					Train			
	Y28	"	No	Yes	SNCF Home Service Carri-		X	
					ages, TEE Trains			
	Y28B	"	No	Yes				
	Y28C	"	No					
	Y28E	"	No		Mistral Paris-Mersailles		X	
	Y28E2	"	No	Yes				
	Y28E3	"	No					
	Y28F	"	No	Yes				
	Y28Q	Schlieren	No					
	Y30	SNCF	No	Yes	Car-Carrier Vehicles			
	Y30P	"	No	Yes	Double Decker Suburban			X
					Coaches			

PASSENGER TRUCK LIST

COUNTRY	TRUCK OR VEHICLE DESIGNATION	TRUCK BUILDER	POWERED	SOME DATA AVAILABLE	SYSTEM USED ON	APPLICATION		
						Transit	Mainline	Commuter
	Y32	SNCF	No	Yes	First Class Coach A9U TEE			X
					and Second Class B11U			
	Y32A	"	No	Yes	TEE A9U Coach European			
					Standard Coach			
	Y32A1	"	No	Yes				
	Y32A2	"	No	Yes				
	Y32B	"	No		B11U Coach - TEE			
	Y32B1	"	No	Yes				
	Y32B2	"	No	Yes				
	Y32E	"	No					
	Y187	"	No					
	Y205	"	No					
	Y207	"	No	Yes				
	Y207A	"	No					
	Y207B	"	No					
	Y207B2	"	No	Yes				
	Y207B3	"	No					
	Y208	"						
	Y214	"	No					
	Y223	"	Yes	Yes	Paris-Caen-Cherbourg Line		X	
					RTG Turbine Train			
	Y224	"	No	Yes	RTG Turbine Train		X	
	Y225	"	Yes	Yes	TGV-.001 Turbine Train		X	
	Y226	"	Yes	Yes	Z-7001			

PASSENGER TRUCK LIST

COUNTRY	TRUCK OR VEHICLE DESIGNATION	TRUCK BUILDER	POWERED	SOME DATA AVAILABLE	SYSTEM USED ON	APPLICATION		
						Transit	Mainline	Commuter
	Y226a		No		Z-7001			
	MF67C3 mono-	MTE	Yes	Yes	Paris Metro	X		
	motor Bogie							
	Eurofa	SNCF	Yes	Yes	Standard Passenger Coaches			
GERMANY	M5	Klochner-Ham-		Yes	First twenty T2 Cars		X	
		boldt-Deutz						
		(Minden Dentz)						
	M6	"		Yes				
	M6-2B	"		Yes	Carel Air Conditioned T2			
					Cars Carel Fouche		X	
	M6-1C	"			T2 & Sleeping Cars		X	
	MD50	"						
	ET420	M.A.N.		Yes				
	ET403	"	Yes	Yes	High Speed German Inter-		X	
					City Network			
	VT614	"	Yes,No					
	ET472/473	MBB Linke-	Yes	Yes	Hamburg			
		Hofmann-Busch						
	DT1	"	Yes		Hamburg Metro			
	DT2	"	Yes	Yes	Hamburg Metro			
	DT3	"	Yes	Yes	Hamburg Metro			
	DuWag U-2	DuWag	Yes, No	Yes	Frankfurt Subway			

PASSENGER TRUCK LIST

COUNTRY	TRUCK OR VEHICLE DESIGNATION	TRUCK BUILDER	POWERED	SOME DATA AVAILABLE	SYSTEM USED ON	APPLICATION		
						Transit	Mainline	Commuter
	Munchen-Kassel	Wegmann	Yes, No		TEE Parsifal Paris-Ruhr			
	WTR-69	"						
	S-WTR-69-1	"	No					
	S-WTR-69-1	"	Yes					
JAPAN	FS308	Sumitomo Metal Ind.	No	Yes	Tobin R.R. Co., Ltd.			
	FS357	"	Yes	Yes	"			
	FS302	"	Yes	Yes	Kcihan Electric Railway Co.			
	FS337B	"	No	Yes	"			
	FS330	"	Yes	Yes	Odakyu Electric Railways			
	FS360	"	Yes	Yes	"			
	FS326	"	Yes	Yes	Nagoya Railroad Co.			
	FS335A	"	Yes	Yes	"			
	FS329A	"	Yes	Yes	Kaisai Electric Railway Co			
	FS329B	"	Yes	Yes	"			
	FS323	"	Yes	Yes	Tcito Rapid Transit Auth.			
	FS358	"	Yes	Yes	"			
	TS101	Tokyu Car Mfg.		Yes				
	TS105	"		Yes				
	TS301	"		Yes				
	TS302	"		Yes				
	TS303	"		Yes				
	TS501	"		Yes				

PASSENGER TRUCK LIST

COUNTRY	TRUCK OR VEHICLE DESIGNATION	TRUCK BUILDER	POWERED	SOME DATA AVAILABLE	SYSTEM USED ON	APPLICATION		
						Transit	Mainline	Commuter
	DT23			Yes				
	KS50	Kisha Seizo			Kcihan Electric Railway			
	TR55	Kaisha						
	TR58			Yes				
	KS51	Kisha Seizo						
		Kaisha						
	KH15	Hitachi			Odakyu Railways			
	KS53							
	FS207	Sumitomo Metal		Yes	Hanshin Electric Ralway			
	KS55	Kisha Seizo			Kcihan Electric Railway			
		Kaisha						
	FS337C	Sumitomo Metal		Yes	Kcihan Electric Railway			
					(Osaka)			
	DT92							
	DT9001	Nippon Sharyo	Yes		New Tokaido Line		X	
		Seizo						
	DT9002	Kisha Seizo	Yes		New Tokaido Line		X	
		Kaisha						
	DT9003	Kinki Sharyo	Yes		New Tokaido Line		X	
	DT9004	Sumitomo Metal	Yes		New Tokaida Line		X	
	DT200			Yes	New Tokaido Line		X	
	DT9005	Kawasaki Roll-	Yes		New Tokaido Line		X	
		ing Stock						
	DT9006	Hitachi	Yes		New Tokaido Line		X	

PASSENGER TRUCK LIST

COUNTRY	TRUCK OR VEHICLE DESIGNATION	TRUCK BUILDER	POWERED	SOME DATA AVAILABLE	SYSTEM USED ON	APPLICATION		
						Transit	Mainline	Commuter
SWITZERLAND	BE4/6	Schindler	Yes, No	Yes	Suburbs and Basell			
	CFF B4	"						
	Y28Q	Schlicren						
	CFFA4 1258	"						
	M2 2e	"						
	LaBrugerize	"		Yes				
	Be 8/8	"	Yes	Yes				
	CFFA4 1255	SIG	Yes	Yes				
	TEE	SIG						
	B 4/8	SIG	Yes, No	YES				
	CFF 1 re	SIG						
ITALY	7170	Fiat						
	Y0160	Fiat		Yes	Systems to Speeds of			
					250 km/hr			
	71	Fiat		Yes	Stock operating at speeds			
					to 200 km/hr			
	7196	Fiat		Yes	Stock operating at speeds			
					to 140 km/hr			
	27A	FS						
	Eurota Bogie	Fiat		Yes	European Standard Coaches			
	Breda Bogie	Breda		Yes				

PASSENGER TRUCK LIST

COUNTRY	TRUCK OR VEHICLE DESIGNATION	TRUCK BUILDER	POWERED	SOME DATA AVAILABLE	SYSTEM USED ON	APPLICATION		
						Transit	Mainline	Commuter
SWEDEN	C1	ASEA	Yes					
	C2	"	Yes					
	C3	"	No					
	C4	"	Yes					
	C5	H and S Orn-	Yes					
		skoldsvik						
	C6	Linkoping	Yes					
	C7	ASEA	Yes					
	C8	"	Yes	Yes	Stockholm Metro	X		
	C9	"						
ENGLAND	BR B4	British Rail			Mark II Coaches		X	
	BR Type II	"						
	BP 8		Yes	Yes				
	BT 10				High Speed Train London-		X	
					Bristol/South Wales			
	APT		Yes, No	Yes			X	
	APT-E		Yes, No	Yes			X	
	C-69	Metro Cammell	Yes, No	Yes	London Transport Executive			
	BR BT 5	British Rail			Mark III Coaches		X	

PASSENGER TRUCK LIST

COUNTRY	TRUCK OR VEHICLE DESIGNATION	TRUCK BUILDER	POWERED	SOME DATA AVAILABLE	SYSTEM USED ON	APPLICATION		
						Transit	Mainline	Commuter
USA	Pioneer III	Budd Company	No	Yes	Lt. Wt. Railcar 3880	(Prototype)	X	X
	"	"	No	Yes	SOREFAME			
	"	"	Yes	Yes	CTA Test Truck (Prototype)			
	"	"	No	Yes	RDC Demo Car		X	X
	"	"	Yes	Yes	P.R.R.			
	"	"	No	Yes	Sorocabana		X	
	"	"	Yes	Yes	SEPTA			X
	"	"	Yes	Yes	BARTD Test Z-401 (Experimental)			
	"	"	Yes	Yes	NYCTA (4 Car Sets)	X		
	"	"	Yes	Yes	4 Test Cars		X	
	"	"	Yes	Yes	GT 1 and GT 2			X
	"	"	Yes	Yes	DRPA (Lindenw ld)	X		
	"	"	Yes	Yes	CTA	X		
	"	"	Yes	Yes	MTA			X
	"	"	No	Yes	L.I.M. Vehicle (Experimental)			
	"	"	Yes	Yes	Sao Paulo	X		
	"	"	No	Yes	AMTRAK		X	
	ASDP Truck	"	Yes	Yes	SOAC	X		
	Cast Steel	Gen'l Steel Ind	Yes	Yes	Cleveland CTS	X		
	"	"	Yes	Yes	Boston MTA tunnel			
	"	"	Yes	Yes	Boston MTA elevated			
	"	"	Yes	Yes	Hudson and Manhattan			
	"	"	Yes	Yes	Chicago CTA	X		
	Inboard Bearing	"	Yes	Yes	New York City MTA			X

PASSENGER TRUCK LIST

COUNTRY	TRUCK OR VEHICLE DESIGNATION	TRUCK BUILDER	POWERED	SOME DATA AVAILABLE	SYSTEM USED ON	APPLICATION		
						Transit	Mainline	Commuter
	General 70-C	General Steel	Yes	Yes	PATH PA-3 Cars			X
		Industries						
	Lt.Wt.Cast	"	Yes	Yes	SOAC	X		
	Alloy							
	Cast Steel	GSI & Buckeye	Yes	Yes	New York City MTA		X	X
	"	"	Yes	Yes	New York City MTA - New		X	X
	"				Haven M-2			
	"	"	Yes	Yes	SEPTA NJ DOT Silverliners IV		X	X
	General 70	GSI	Yes	Yes	Boston (MBTA)	X		
	"	"	Yes	Yes	Metroliner		X	
	Cast Steel	Adirondack	Yes	No	Philadelphia Market-Frank-			
					ford Subway Surface Cars			
	"	Adirondack	Yes	No	New York City M.T.A.			
	HPT-2	Rockwell	Yes	Yes	NYCTA R-46	X		
	HPT-3	Rockwell-LFM	Yes	Yes	BARTD	X		
	HPT-4	Rockwell	Yes	Yes	Washington Metro	X		
	MPT-2	LFM-Rockwell	Yes	Yes	Cleveland	X		
	-	Wegmann	Yes	Yes	CTA	X		
	-	Tokyn Car	Yes, No	Yes	MBTA, SLRV San Francisco	X		
		Rockwell	Yes		ACT-1	X		
	Metroliner	SIG	Yes	Yes	Northeast Corridor		X	
	Truck							

PASSENGER TRUCK LIST

COUNTRY	TRUCK OR VEHICLE DESIGNATION	TRUCK BUILDER	POWERED	SOME DATA AVAILABLE	SYSTEM USED ON	APPLICATION		
						Transit	Mainline	Commuter
AUSTRALIA	Budd-Comeng P-III Type	Commonwealth Engineering (NSW) Pty.Ltd.	Yes		Comeng Electric Rapid Transit	X		
	"	"	Yes		Western Australian Government Railways (Perth and Kalsoarlic)		X	
CANADA	Cast Steel Alloy	Dominion and Foundries Co. (Dofasco)	Yes	Yes	Toronto Transit Commission	X		
		"		Yes	LRC		X	
				Yes	UACL - United Aircraft of Canada Ltd, Northeast Corridor and Canada		X	
RUSSIA	ER 200		Yes, No	Yes	Moscow-Lenigrad		X	

2.2 High Speed Trucks

The passenger truck list just provided in section 2.1 has been condensed to include selected high speed trucks for which engineering data will be presented and they are as follows:

French:	Y-28 Y-32 Y-224 Y-225 Y-226
Italian:	Fiat Eurofa Z 1040
German:	ET-403 Minden Deutz
Japan:	DT 200
Canadian	LRC
British:	BT 10
Russian:	ER 200
U.S.:	P- III Metroliner

The above high speed trucks have been included because the most complete data tabulations could be provided. All of the trucks or vehicles are designed for 125 mph (200 kmh) or higher except for the U.S. P-III (Amcoaches) which are locomotive hauled and designed for 120 mph (193 kmh).

3. TRUCK SUMMARY

3.1 General Truck Characteristics

The basic design characteristics of the high speed trucks listed in Section 2.2 are presented in Table 1. The design parameters included are conventional yaw pivot, soft primary suspension, rigid truck frame, powered, swing hanger design, air spring secondary suspension, roll bar, active tilt control, equalizer beam, articulated train, and electromagnetic brakes.

The conventional yaw pivot denotes a truck with a center pin arrangement between the truck and the car body which allows the car body to rotate with respect to the truck.

A soft primary suspension is a primary vertical suspension having the vertical bounce resonance of the truck on its springs of 8 Hz or less. The calculation of this resonant frequency considers the two degree-of-freedom system of the car body on its vertical springs coupled with the truck on its vertical springs. Typical practice is a 1 Hz secondary.

A rigid truck frame is a truck frame which is considered to have no flexibilities, and a powered truck is one which has motors attached to the truck, either axle mounted or frame mounted.

A swing hanger design is one which has swing links connecting the truck frame with the bolster which allows the truck to move laterally. This movement provides the secondary lateral suspension of the vehicle.

Air spring secondary suspension pertains to a truck having air springs in the secondary suspension.

A roll bar is a device by which additional secondary roll stiffness can be provided for systems not having enough stiffness from the secondary springs.

Active tilt control applies to those vehicles having a system where a device such as an accelerometer is used to sense acceleration levels and when these levels become too high the tilting mechanism is activated.

An articulated train applies to those trucks where the ends of two car bodies rest on a single truck.

An equalizer beam truck is one where equalization of the truck is provided by the equalizer beam and its springs. This configuration allows the springs to be mounted longitudinally inboard of the wheels. Electromagnetic brakes refer to trucks which have brakes which react with the rail.

3.2 Summary of Truck Designs

The basic design characteristics of the high speed trucks tabulated in Section 3.2 are presented in the Truck Summary Table on the following page. The first parameter included is conventional yaw pivot which is composed of a center pivot arrangement. Trucks such as the Y-28 and Y-32 which utilize resiliently mounted traction linkages are not considered conventional yaw pivot.

A soft primary suspension is considered to apply to systems having a truck bounce frequency less than 8 Hz. The P-III and the Metroliner are distinguished from the other 13 trucks since they have truck bounce frequencies of about 26 Hz and 10 Hz, respectively. Another category is a rigid truck frame. All of the trucks shown have rigid frames except for the P-III which is an articulated frame with independent side frames.

Other features included in the table are powered, swing hanger design, air spring secondary, and roll bar. From the trucks presented, there are five powered trucks and four swing hanger designs. Half of the trucks utilize air springs for the secondary suspension, and four have roll bars.

The one truck with active tilt control is the Canadian LRC. This particular vehicle has an accelerometer to detect lateral vibration levels. When these levels become too high, the tilting mechanism is activated.

The Y-225 is the only truck used in an articulated train, which is a vehicle having the ends of two passenger cars resting on a single truck.

The Metroliner is the only equalizer beam truck of the fifteen high speed trucks.

There are nine trucks which have electromagnetic brakes.

TABLE 1

TRUCK SUMMARY

Truck Type	Conventional Yaw Pivot	Soft Primary Suspension	Rigid Truck Frame	Powered	Swing Hanger Design	Air Spring Secondary Suspension	Roll Bar	Active Tilt Control	Artic-ulated Train	Equalizer Beam	Electromag-netic Brake
Y-28		X	X		X		X				X
Y-32		X	X				X				X
Y-224		X	X								X
Y-225		X	X	X		X			X		X
Y-226		X	X								X
Fiat Eurofa		X	X				X				X
Z1040	X	X	X	X	X						
ET403		X	X	X		X					X
Minden Deutz	X	X	X		X		X				X
DT200	X	X	X	X		X					
LRC		X	X			X		X			
BT10	X	X	X		X	X					
ER200	X	X	X	X		X					X
P-III	X					X					
Metroliner	X	X	X	X		X				X	

4. TRUCK AND CAR DATA COLLECTION

4.1 Truck Description and Illustration

A description and a spring-mass-damper sketch of each high speed truck mentioned in Section 2.2 are presented in the following pages. Wherever available, a brief history is given indicating such things as maximum speed attained, the train consist, and other significant features of the particular vehicle.

The following sumbols are used in the sketches:

 - primary suspension three directional flexibility and inherent damping

 - elastic element and inherent damping

 - viscous damping element

 - carbody connection

Definitions of terms contained in the descriptions and sketches are as follows:

Anchor rod	-	a bar which takes longitudinal loads and is located either between the bolster and carbody or bolster and truck frame. There are two of these per truck.
Bolster	-	a load bearing crossmember which is not rigidly connected to the truck frame.
Equalizer bar	-	a member located in the center of a truck which the center pivot connects to.
Equalizer beam	-	equalization of the truck is provided by this structural piece and its springs. There are two equalizer beams per truck.
Roll bar	-	is a bar which is mounted in a manner which provides additional roll stiffness to the secondary suspension.

Slide pad	-	allows rotational motions to occur between the slider and the carbody.
Swing link	-	a link which permits lateral motions to occur and provides the lateral secondary suspension stiffness.
Traction linkages	-	linkages which take braking loads.

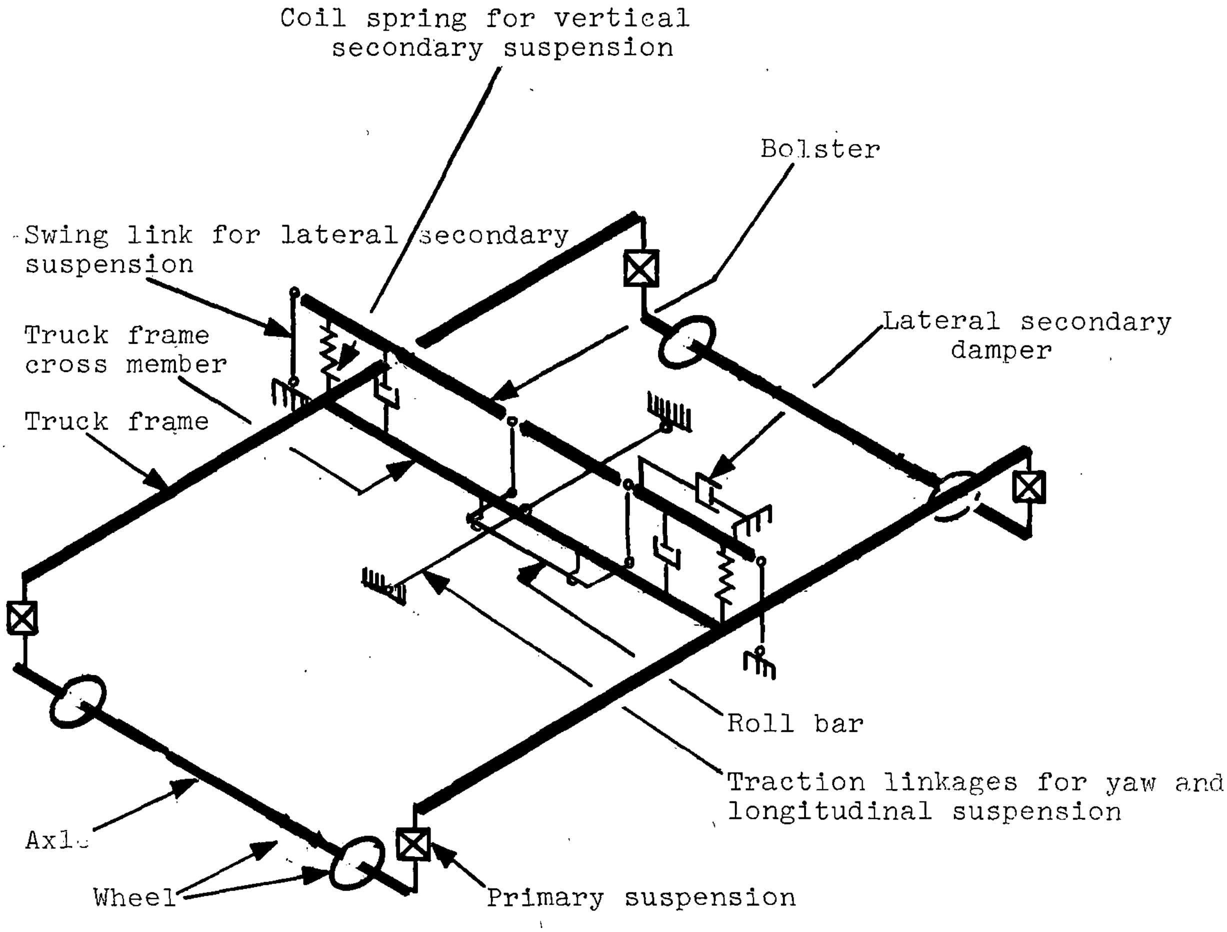
The Y-28 truck is used on the Trans European Express (TEE) coaches for 200 km/hr service. The primary suspension is composed of four groups of coiled springs and four groups of silentbloc materials of considerable size. Each group is located outboard of the wheels. The silentbloc material which connects the axle to the truck frame provides sufficient stiffness in the lateral and longitudinal direction to keep the axles relative to the truck frame, and in the vertical direction adds to the stiffness of the coil springs.

The secondary vertical suspension is made up of two groups of two coiled springs per truck, each group being represented in the sketch by a single elastic element and two hydraulic shock absorbers to control the vertical movements. There are two swing links between the body and bolster which are articulated at the lower end to two body brackets represented by a ground connection. These swing links are located in line with the lateral axis of the truck and provide the lateral suspension. There is a lateral shock absorber to control the lateral displacement between the body and the truck.

A roll bar helps to control the rolling motions between the truck frame and bolster, and is supported under the truck frame cross member and connected by links to the bolster.

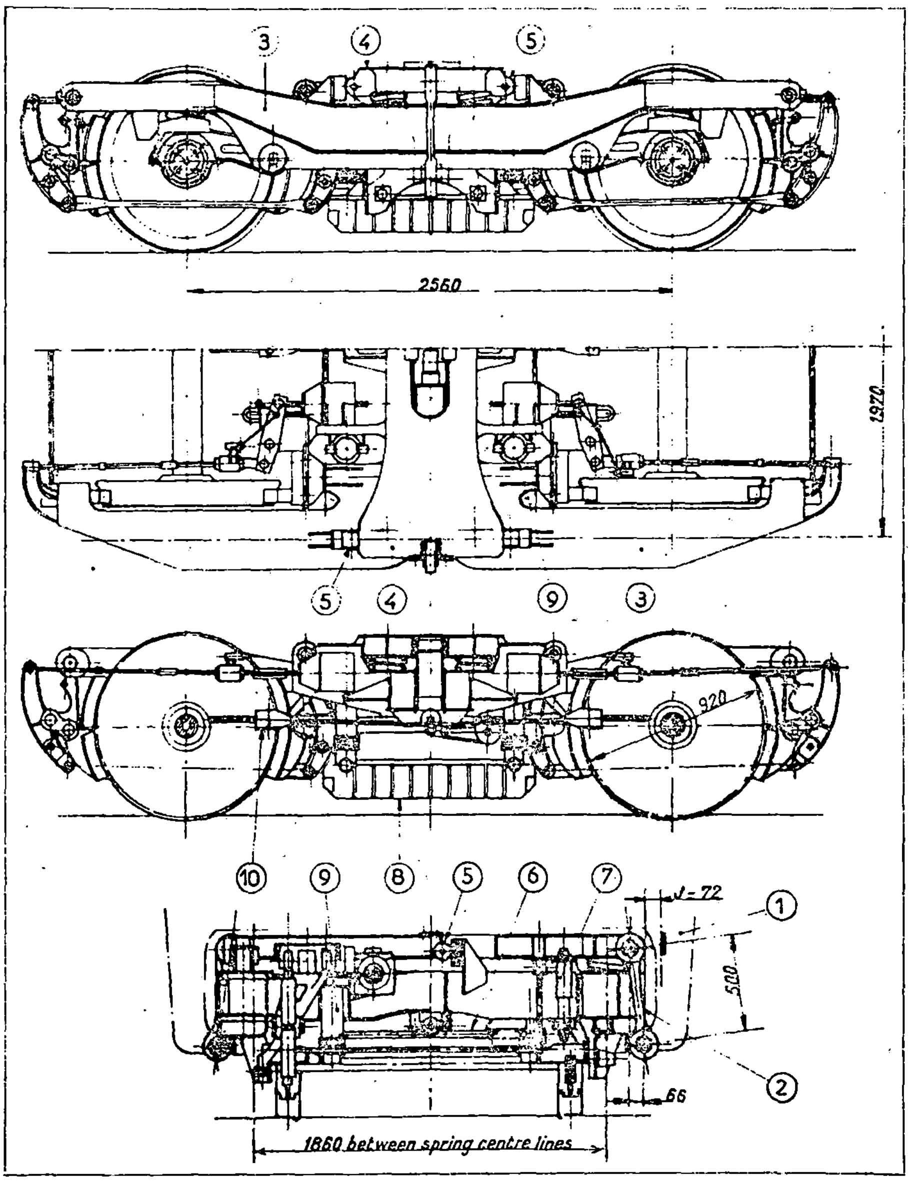
The Y-28 truck has no conventional yaw pivot for steering. It is driven by means of traction linkages arranged longitudinally between the truck frame and two crutches forming part of the body represented by ground connections. The connection is more or less at axle level. These traction linkages have resilient attachments to relieve the linkages of shock loads. The resilient attachment includes helical spring and Belleville washers, resulting in progressively varying degree of elasticity. Stops engage if force in wire rope reaches 12 metric tonnes which is rare. The ultimate tensile strength is 24 tonnes.

The vertical and lateral car body loads are transmitted through car body brackets to the swing links into the secondary suspension. Then the load passes through the truck frame and the primary suspension. The longitudinal load path proceeds from the carbody crutches or brackets represented in the sketch by ground connections through the traction linkages to the truck frame and finally goes out through the primary suspension.



Coil spring for vertical secondary suspension
Bolster
Swing link for lateral secondary suspension
Truck frame cross member
Truck frame
Lateral secondary damper
Roll bar
Traction linkages for yaw and longitudinal suspension
Axle
Wheel
Primary suspension

Figure 1



1. Body bracket — 2. Swing link — 3. Bogie frame of welded plate. Ends of solebars in cast steel — 4. Bolster — 5. Guide rollers for bolster — 6. Anti-roll bar — 7. Vertical damper — 8. Electromagnetic brake shoe — 9. Brake shoe suspension — 10. Wire rope connecting the bodie frame to the body.

Figure 2

Courtesy of French Railway Techniques

Y - 32

The Y-32 truck is designed for the European standard truck and for speeds in excess of 125 mph.

The primary suspension is composed of four steel coiled springs for vertical stiffness. Flexible connections between the axlebox and truck frame result in three-dimensional flexibility which gives longitudinal and lateral stiffness, and in the vertical direction adds to the stiffness of the coil springs to provide the required vertical spring rate. There are four hydraulic shock absorbers on the truck to restrict vertical motions.

The secondary suspension consists of two long helical springs for vertical stiffness. In addition, these helical springs provide for lateral suspension of the body, and enable the truck to rotate. There are hydraulic dampers controlling the vertical and lateral movements of the coach in relation to the truck.

The truck has a unique feature because there is no conventional center pivot. The connection between truck and body is made by traction linkages located at axle level and resiliently attached to the carbody to permit vertical and lateral motions of the truck across the secondary suspension.

The truck has a roll bar fitted between the truck frame and the carbody to provide additional roll stiffness. A yaw damping arrangement relying on the truck rotating in relation to the body is also a feature of this truck, and only damps yaw rotational motions.

The carbody vertical and lateral loads are transmitted through the long helical springs into the truck frame and go out the primary suspension.

The longitudinal loads proceed from the carbody brackets through the traction linkages into the truck frame and out the primary suspension.

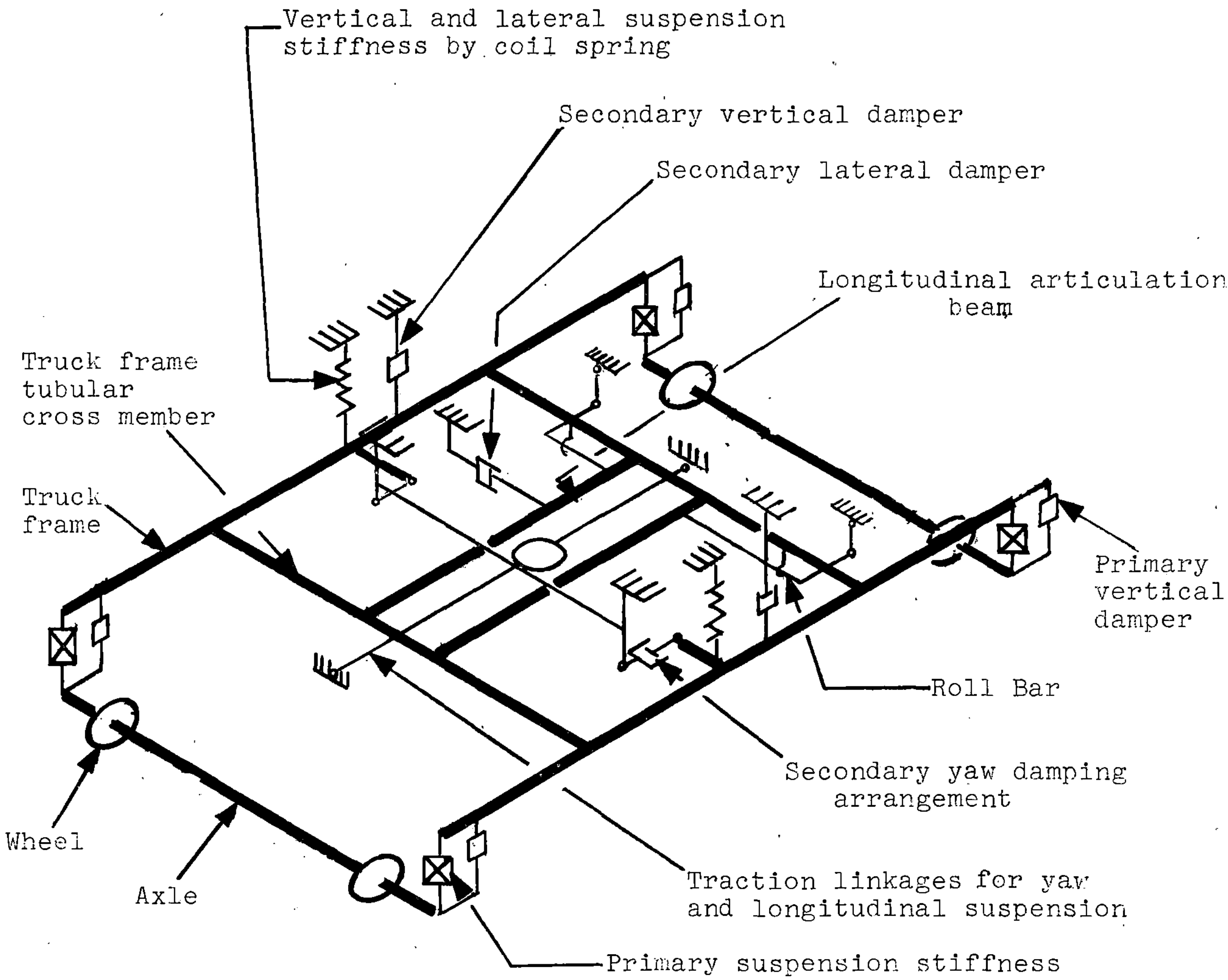
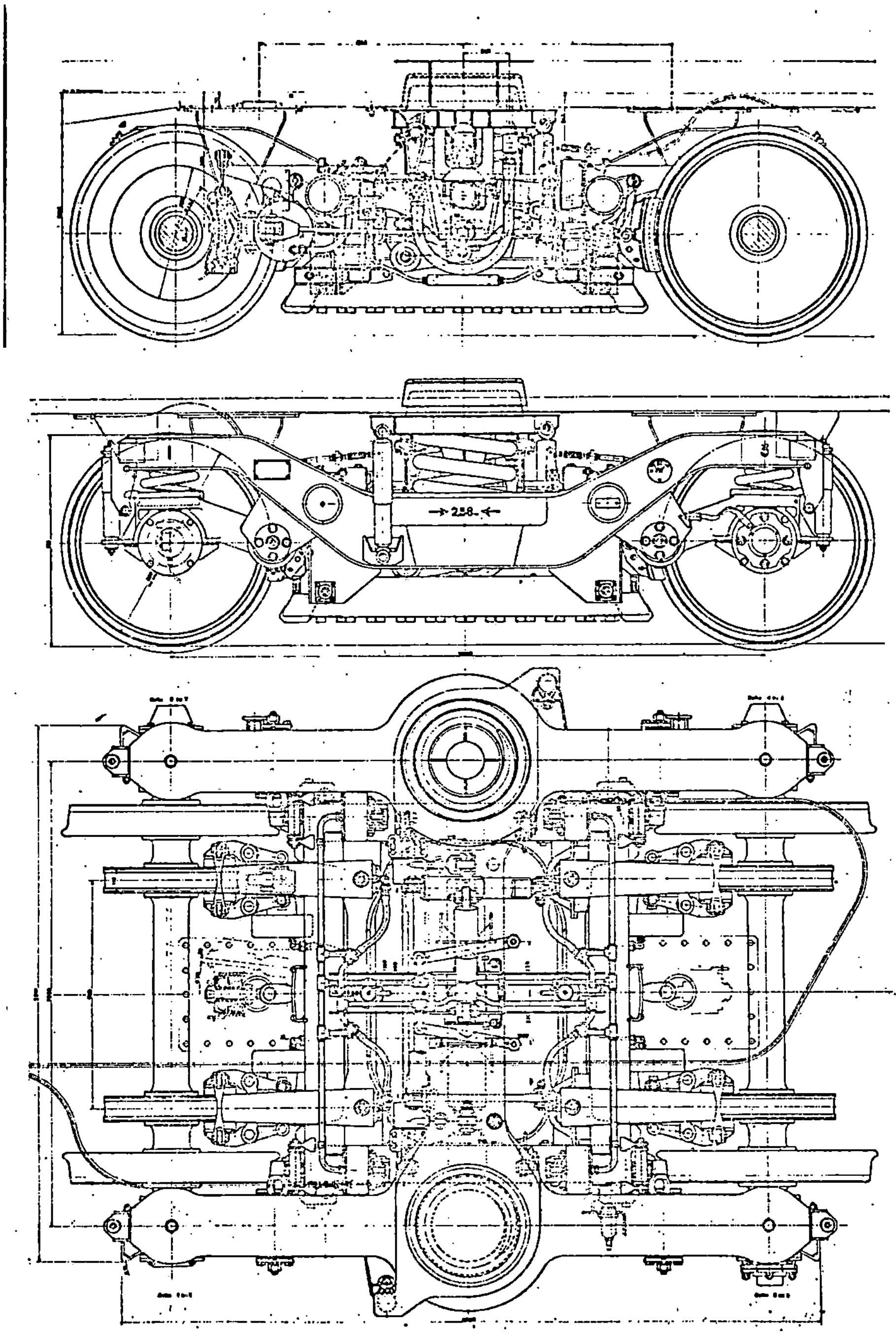

Vertical and lateral suspension stiffness by coil spring
Secondary vertical damper
Secondary lateral damper
Longitudinal articulation beam
Truck frame tubular cross member
Truck frame
Primary vertical damper
Roll Bar
Secondary yaw damping arrangement
Wheel
Axle
Traction linkages for yaw and longitudinal suspension
Primary suspension stiffness

Figure 3

Y-32



General arrangement, bogie type S

Courtesy of Rail Engineering International

Figure 4

French Y-224

The Y-223 and Y-224 trucks are used on the R.T.G. French turbotrain. The turbotrain is composed of two turbine power cars at the ends of three intermediate trailer cars. Each turbine power car rests on one powered Y-223 truck, and one unpowered Y-224 truck. The trailer cars, rest on the Y-224 truck; however, both trucks are quite similar. Data will be supplied for the Y-224 trailer car truck. The R.T.G. train sets went into regular service in May, 1973.

The Y-224 primary vertical suspension consists of four sets of helical springs resting on axleboxes and in series with a rubber disc to absorb the track noise. The axleboxes are connected to the truck frame by rubber bushed links which provide the lateral and longitudinal stiffnesses. There are four vertical hydraulic shock absorbers.

The secondary suspension uses two Saint-Urbain springs (rubber inside steel coil), per truck, which act both as vertical suspension and lateral control and permit the rotation of the truck. Vertical and lateral damping are by hydraulic dampers. There are two longitudinal dampers.

Two rubber-bushed rods, connected to the truck frame and to an equalizer bar which is connected to the body pivot through a rubber ring, transmit the tractive effort to the body.

The vertical and lateral loads are transmitted from the car body to the helical springs with rubber inside through the truck frame and is taken out by the primary suspension.

The longitudinal load is transmitted from the carbody through the center pivot to the equalizer bar and the rubber bushed rods into the truck frame and out the primary suspension.

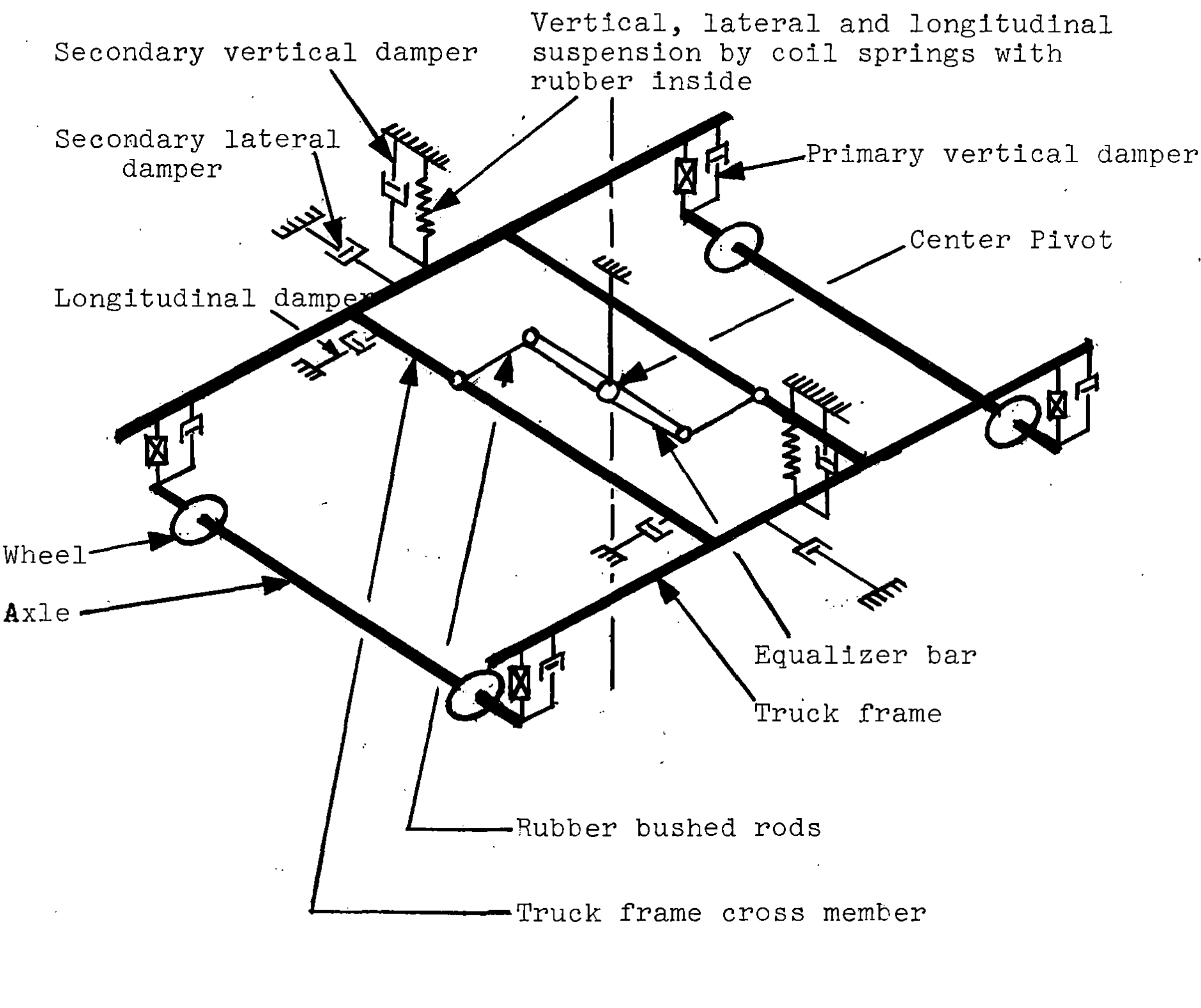

Secondary vertical damper
Vertical, lateral and longitudinal suspension by coil springs with rubber inside
Secondary lateral damper
Primary vertical damper
Center Pivot
Longitudinal damper
Wheel
Axle
Equalizer bar
Truck frame
Rubber bushed rods
Truck frame cross member

Figure 5

Y-224

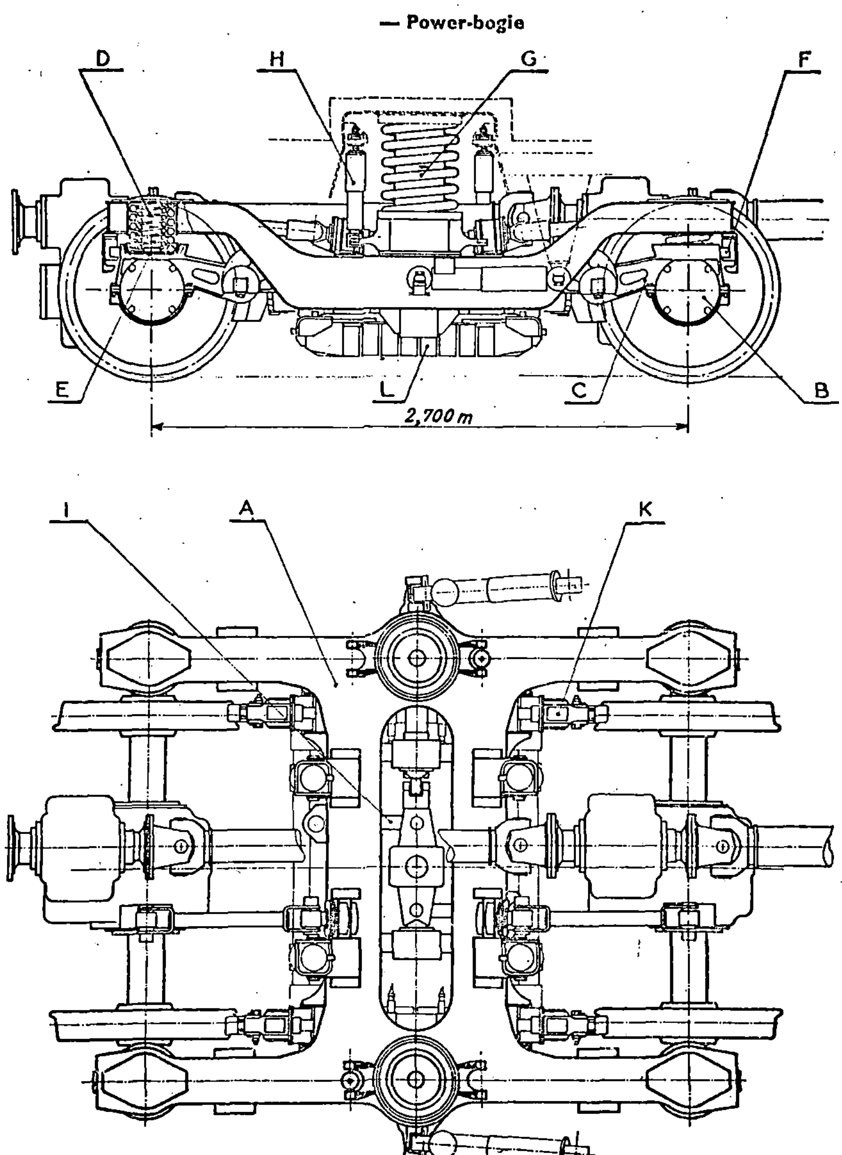


Figure 6

Courtesy of French Railway Techniques

Y-225

The Y-225 truck which is used on the French turbotrain TGV-001 (production versions will use a Y-229 B truck similar to the Y-226 with a 3 meter wheelbase according to a current report) is designed for speeds in excess of 125 mph. In a test run in December of 1972, the TGV-001 hit a speed of 318 km/hr or 199 mph. By December 1974, TGV-001 had run more than 16000 km at speeds greater than 260 km/hr and had made over one hundred runs at more than 300 km/hr. The TGV-001 is composed of two power cars with three trailer cars between them. The five cars are supported on six trucks, all of which are powered. The TGV is an articulated train.

The primary suspension consists of eight sets of helical springs per truck resting on the axlebox brackets and in series with rubber bearers which insulate the body from sound vibrations. This suspension system provides vertical, lateral, and longitudinal stiffnesses. Four hydraulic anti-pitching dampers complete the system.

The secondary suspension consists of two Sumiride air springs per truck. One air spring is on each side of the truck and rests on a bearer on the lateral suspension. Two lateral links per bearer ensure that the air springs operate vertically only. The vertical damping comes from the air springs. The air systems for the two springs are connected by a differential valve to ensure that in the event of failure of one of the springs, the car body will drop vertically on two rubber stops which are not shown in the sketch.

The secondary lateral suspension is made up of four Kleberman Colombes metal rubber sandwiches per truck installed in sets of two giving a frequency of .8 Hz. These four sandwiches are represented in the sketch by four elastic elements. The deformation of the sandwiches in shear permits the rotation of the truck in relation to the body. Two stops, which are not represented in the sketch, each exerting its effort gradually, limit the total lateral displacement between car and body to $\pm$ 80 mm or 3.17 inches. A hydraulic shock absorber provides control of lateral movements.

There is a yaw damping arrangement in the secondary suspension which is composed of a bar with hydraulic dampers connected to the car body, and this is located on both sides of the truck as shown in the sketch. This device also keeps the truck on the line bisecting the angle between two adjacent car bodies.

The vertical load is transmitted from the carbody through the air springs into the rubber sandwiches to the truck frame, and then is taken out through the primary suspension.

The lateral load goes from the carbody through the lateral links and the rubber sandwiches to the truck frame and out the primary suspension.

The longitudinal load goes from the body through the T-shaped member in the center part of the truck into the truck frame central, cross member and then out the primary suspension. This T-shaped member is resiliently mounted within the truck central cross member and is restrained laterally and longitudinally, but allows vertical motions.

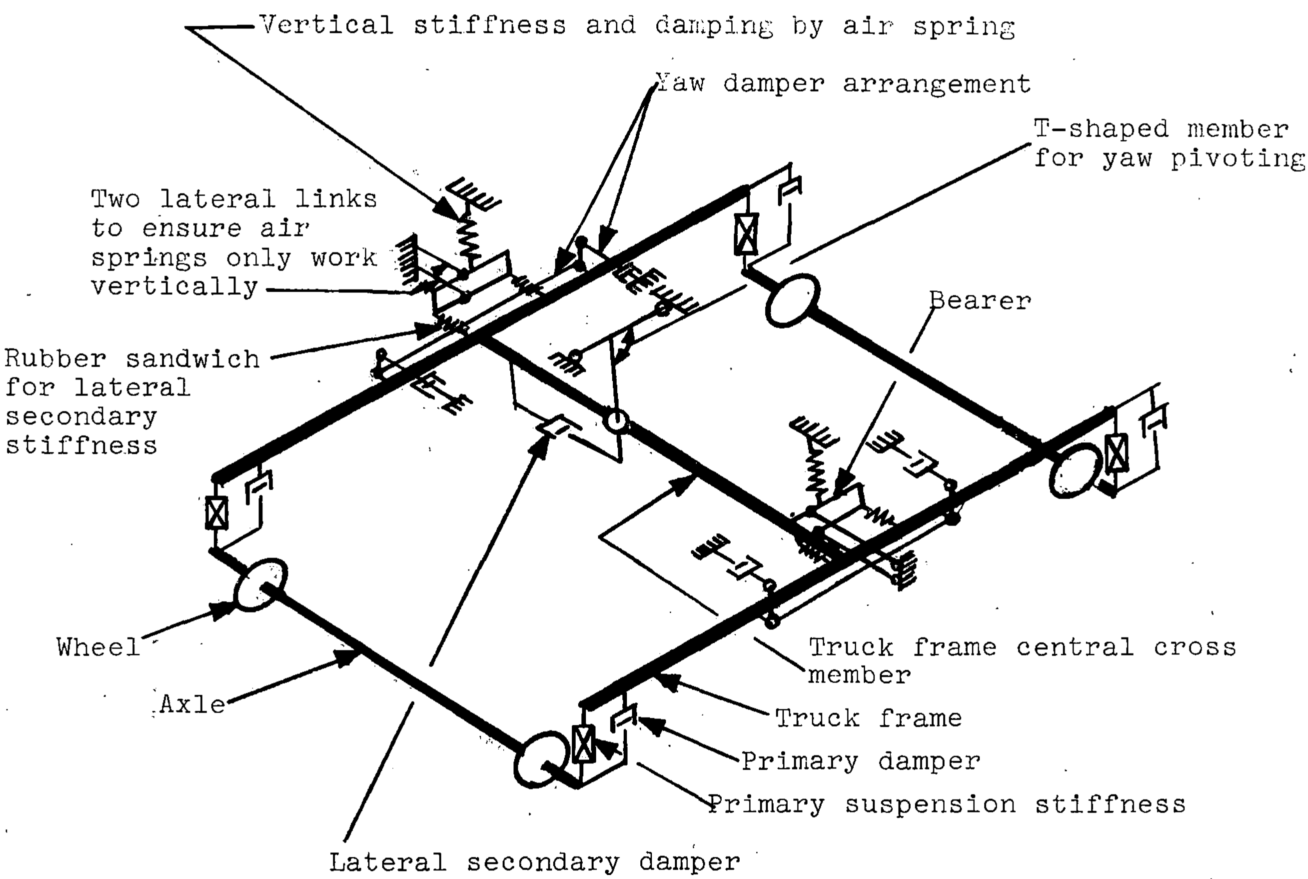
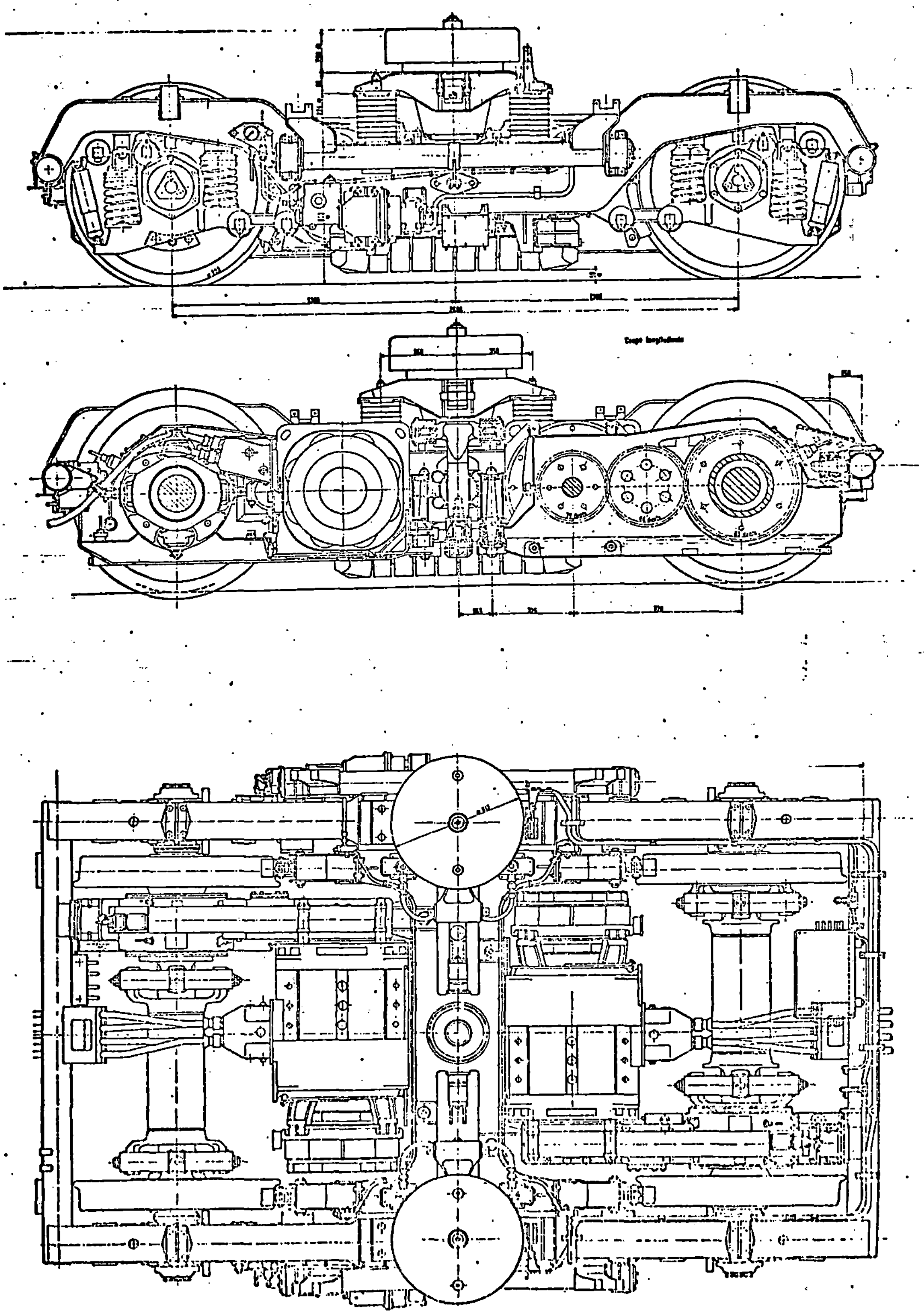

Vertical stiffness and damping by air spring
Yaw damper arrangement
T-shaped member for yaw pivoting
Two lateral links to ensure air springs only work vertically
Bearer
Rubber sandwich for lateral secondary stiffness
Wheel
Axle
Truck frame central cross member
Truck frame
Primary damper
Primary suspension stiffness
Lateral secondary damper

Figure 7

Y-225



Courtesy of French Railway Techniques

Figure 8

French Y-226

The Y-226 truck is used on experimental motor coach No. Z7001. Since entering service in April of 1974, motor coach Z7001 had run 125000 km by the end of January 1975 and made over 100 runs at speeds between 250 and 306 km/hr.

The primary vertical suspension system consists of eight helical springs, and four vertical hydraulic dampers. Two vertical guides on the Y-226 fit into brackets in the axlebox casting and the primary longitudinal and lateral suspension consists of alternate steel and rubber rings around these guides. This arrangemnt allows the stiffness to be varied in the longitudinal and lateral directions.

The secondary suspension is composed of two large helical springs enclosing a rubber cylinder located at the ends of the truck frame central cross member. This system allows vertical, lateral and rotational motions and four hydraulic dampers restrict vertical motions. Rubber stops are arranged to provide progressively increasing resistance so that the lateral truck body movements are limited to 70 mm or 2.77 inches and these stops are not shown in the sketch. There is one lateral and two longitudinal dampers per truck. The truck rotation is limited by four stops.

The vertical and lateral loads are transmitted from the car through the long, helical springs with rubber inside into the truck frame and out the primary suspension.

The longitudinal loads are taken through the center pivot into the truck frame and out the primary suspension.

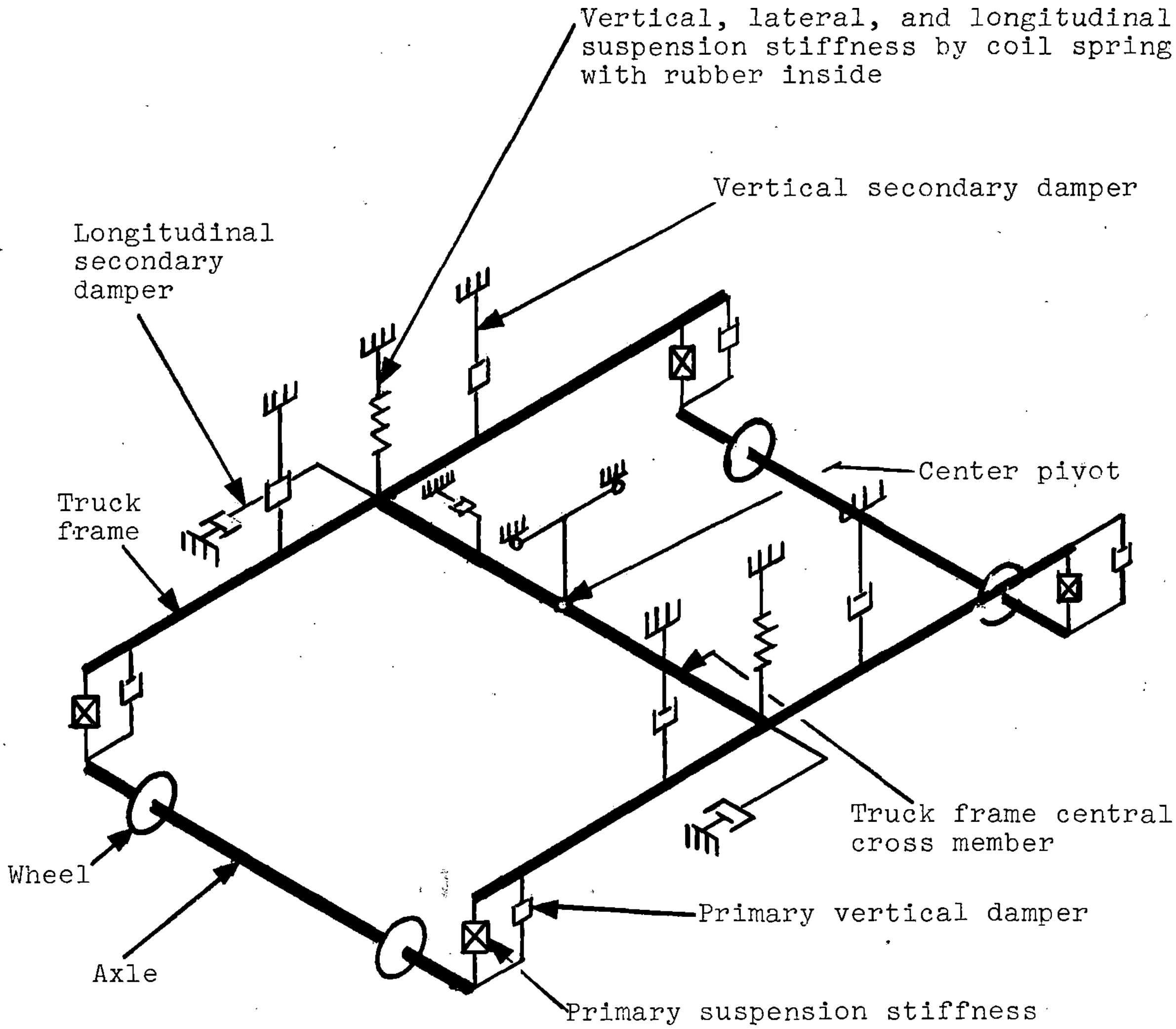
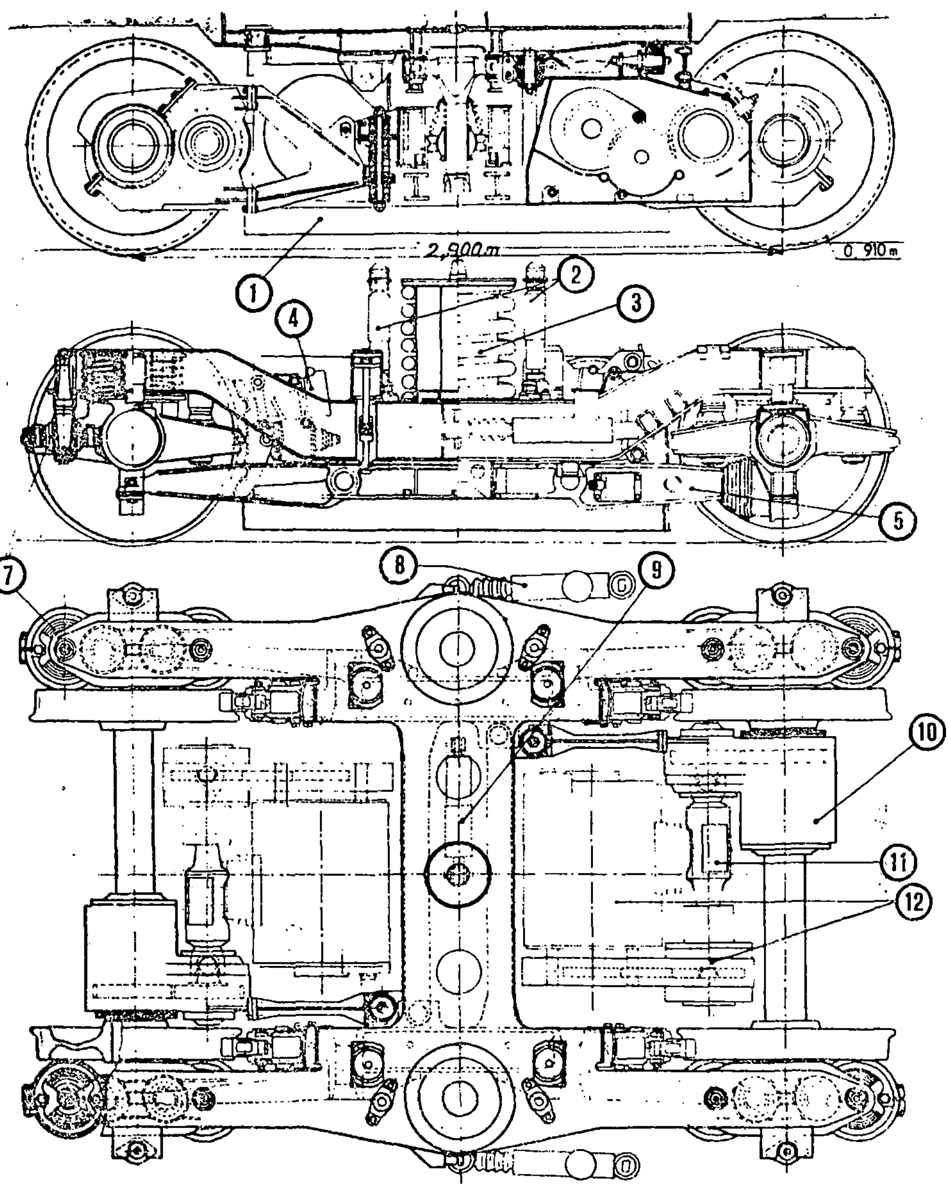
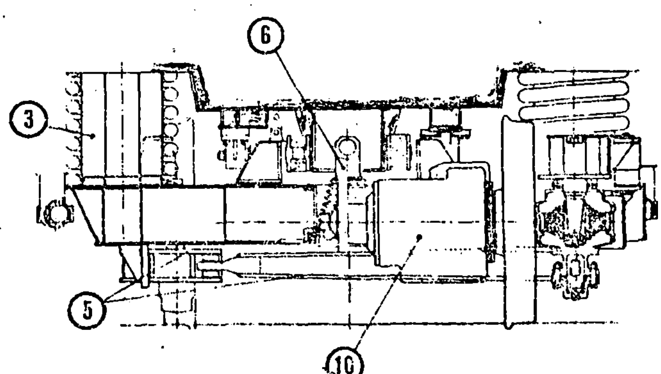

Vertical, lateral, and longitudinal suspension stiffness by coil spring with rubber inside
Vertical secondary damper
Longitudinal secondary damper
Truck frame
Center pivot
Truck frame central cross member
Wheel
Axle
Primary vertical damper
Primary suspension stiffness

Figure 9

Y-226





1. *Linear eddy current brake;*
2. *Dampers in the secondary suspension;*
3. *Secondary suspension;*
4. *Brake equipment;*
5. *Beam supporting the linear brake;*
6. *Member transmitting forces between vehicle body and bogie;*
7. *Primary suspension;*
8. *Anti-hunting damper;*
9. *Transverse damper;*
10. *Driving gearing (reduction ratio: 1.15);*
11. *Sliding tripod transmission;*
12. *Traction motor and reduction gearing (mounted, beneath the vehicle body, reduction ratio: 1.39).*

Courtesy of French Railway Techniques

Figure 10

FIAT Eurofa

This Fiat truck is similar to the Y-32 truck previously described. Both the Y-32 and Fiat were designs for the European standard, and are capable of speeds in excess of 125 mph.

The primary suspension of the Fiat is composed of four helical coiled springs to provide vertical stiffness and flexible connections between the axlebox and truck frame to provide longitudinal and lateral stiffnesses represented in the sketch by one symbol labeled primary suspension. There are four hydraulic shock absorbers for restricting vertical motions.

The secondary suspension consists of two helical springs capped by rubber and located over the truck side frames. These helical springs provide both vertical and lateral suspension stiffnesses. There are two hydraulic dampers controlling the vertical movements and two controlling the lateral movements.

The truck has a rollbar to provide additional roll stiffness and a yaw damping arrangement to control yaw rotational motions which are fitted between the truck and the carbody.

The vertical and lateral loads are transmitted from the carbody through the helical springs into the truck frame and out the primary suspension.

The longitudinal load path follows the center pin through the equalizer bar and links into the truck frame and goes out the primary suspension.

FIAT EUROFA

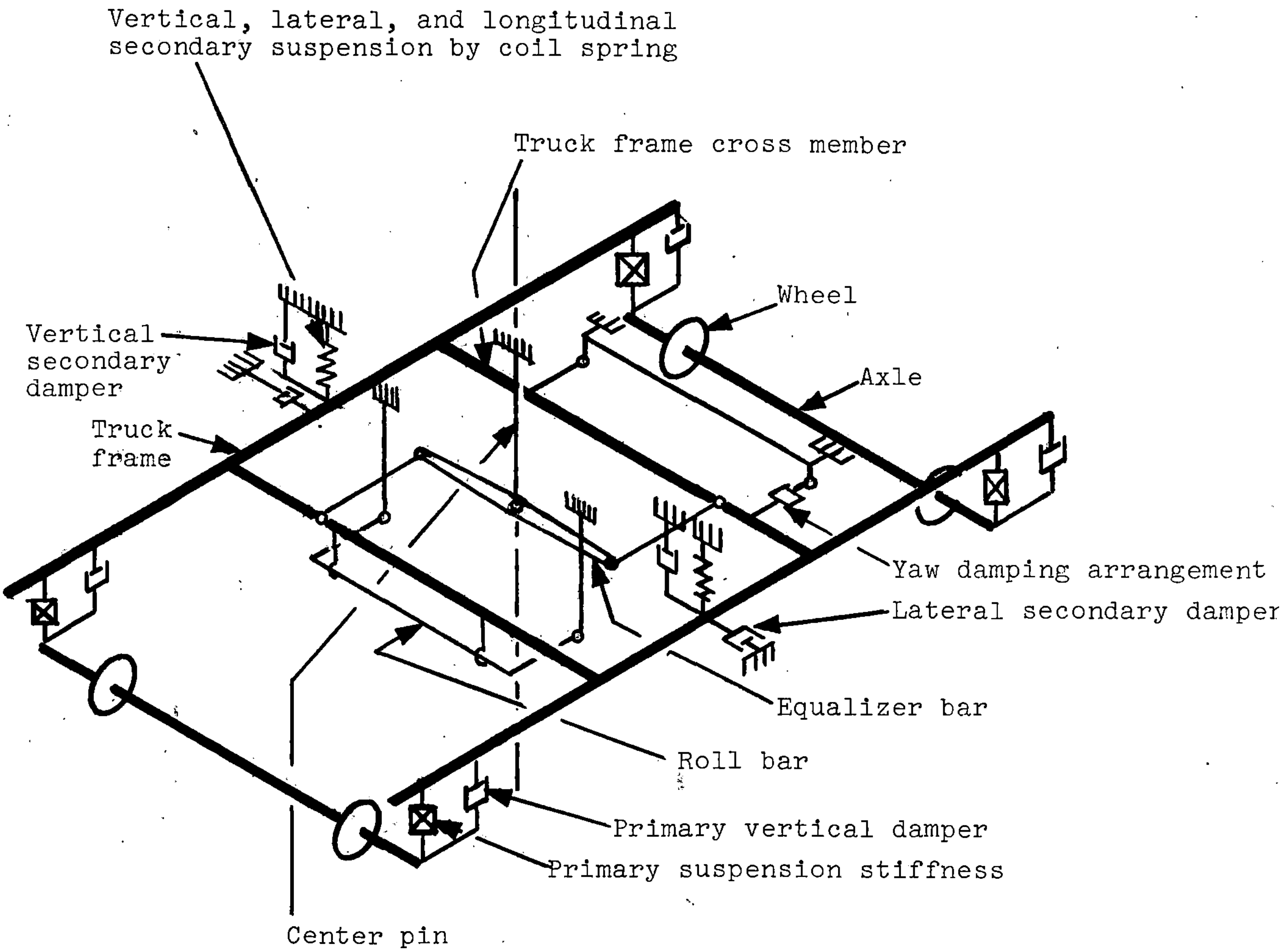
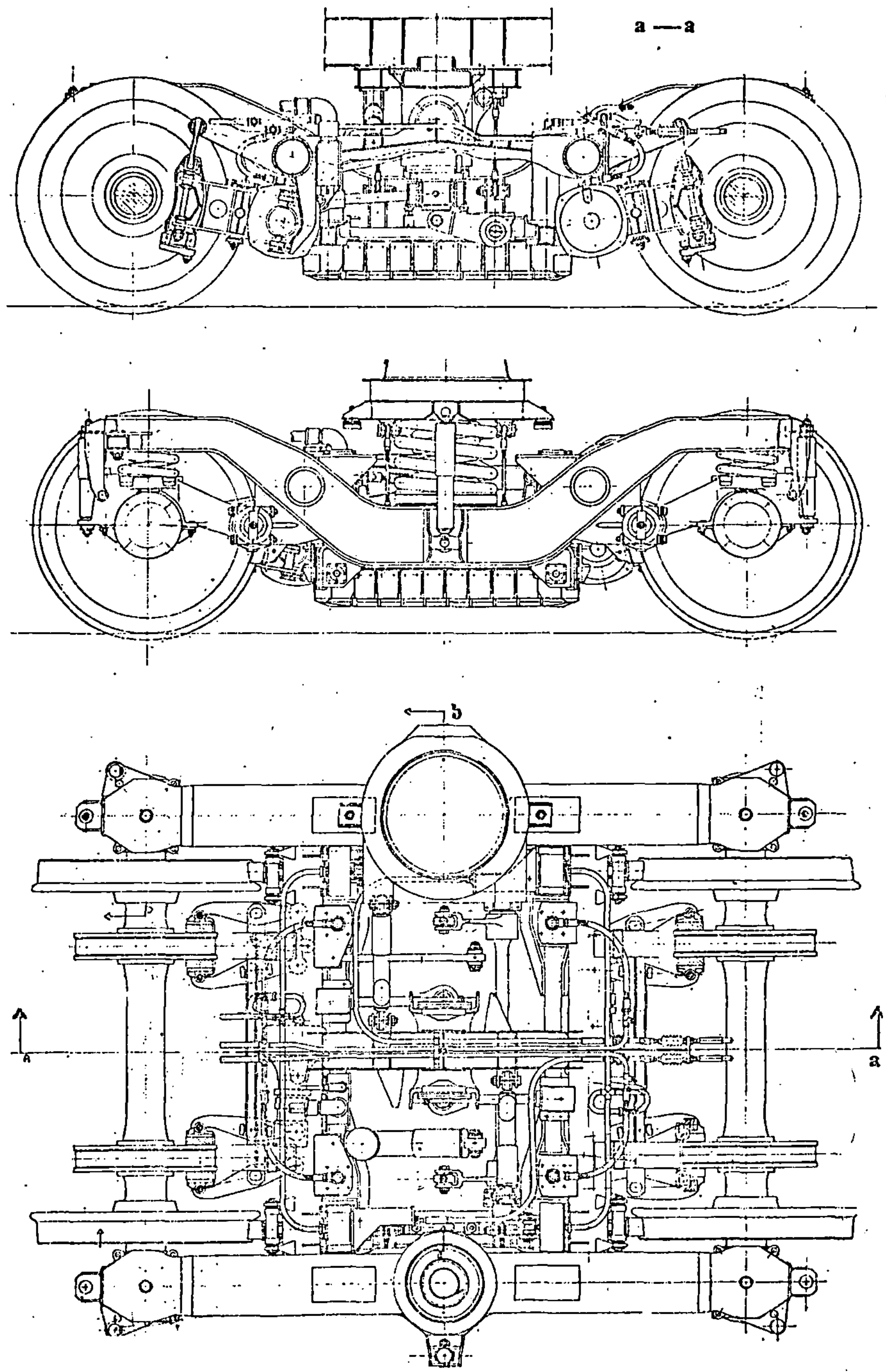


Figure 11

FIAT EUROFA



Courtesy of <u>Rail Engineering International</u>

Figure 12

Italian Z 1040

The Z 1040 trucks are used on the Italian State Railway's improved ALe601 electric motor coaches designed for 200 km/hr. The truck is a swing hanger type design and is powered.

The primary suspension consists of eight helical springs for vertical stiffness. Inside the helical springs are mounted concentric vertical tubes containing rubber segments, internal springs, and phenolic plastic bearings. This arrangement provides lateral and longitudinal stiffnesses and also damping of the primary helical springs because of friction between the phenolic plastic and the vertical tubes. The primary damping is represented by the symbol for viscous damping in the sketch.

The secondary suspension is composed of four helical springs for vertical stiffness, located between the bolster and spring plank, and four swing links for lateral stiffness. The bolster and spring plank is represented by an area in this particular sketch. Damping of the secondary is obtained by two vertical and four lateral hydraulic dampers, only two lateral dampers are shown in the sketch.

The car body rests on the bolster with a center pin to allow for rotational motions.

There are two truck frame cross members located close to the center of the truck which are not shown in the sketch.

The vertical load is transmitted from the carbody through the slide pads and center pivot through the bolster into the secondary vertical suspension down to the spring plank through the swing link to the truck frame, and finally out the primary suspension.

The lateral load is transmitted from the carbody through the center pin into the bolster and coil springs to the spring plank. It then goes through the swing links to the truck frame, and finally out the primary suspension.

The longitudinal load follows the center pin to the center pivot through the bolster, and then through a rod connected between the bolster and truck frame. The longitudinal load then goes out the primary suspension.

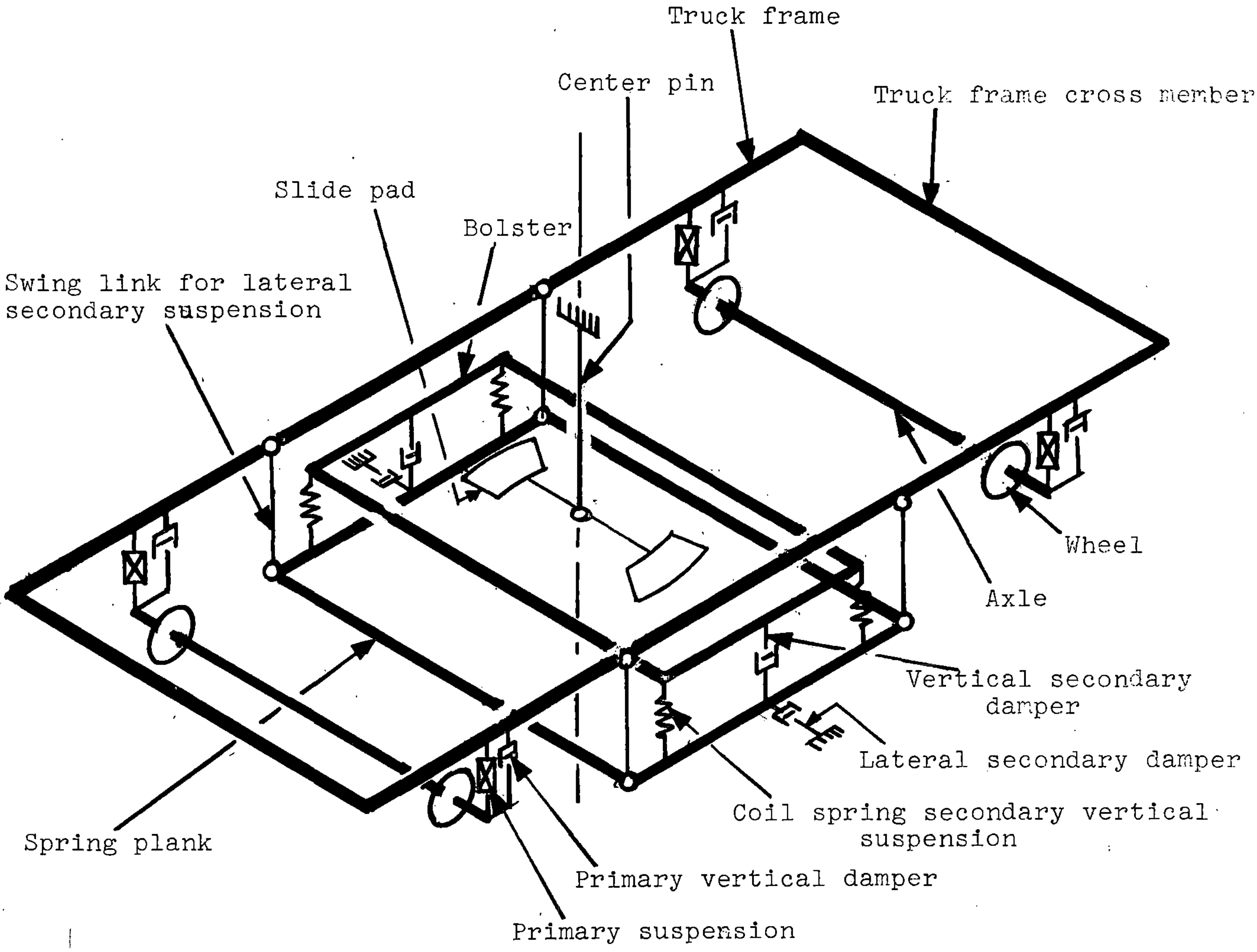
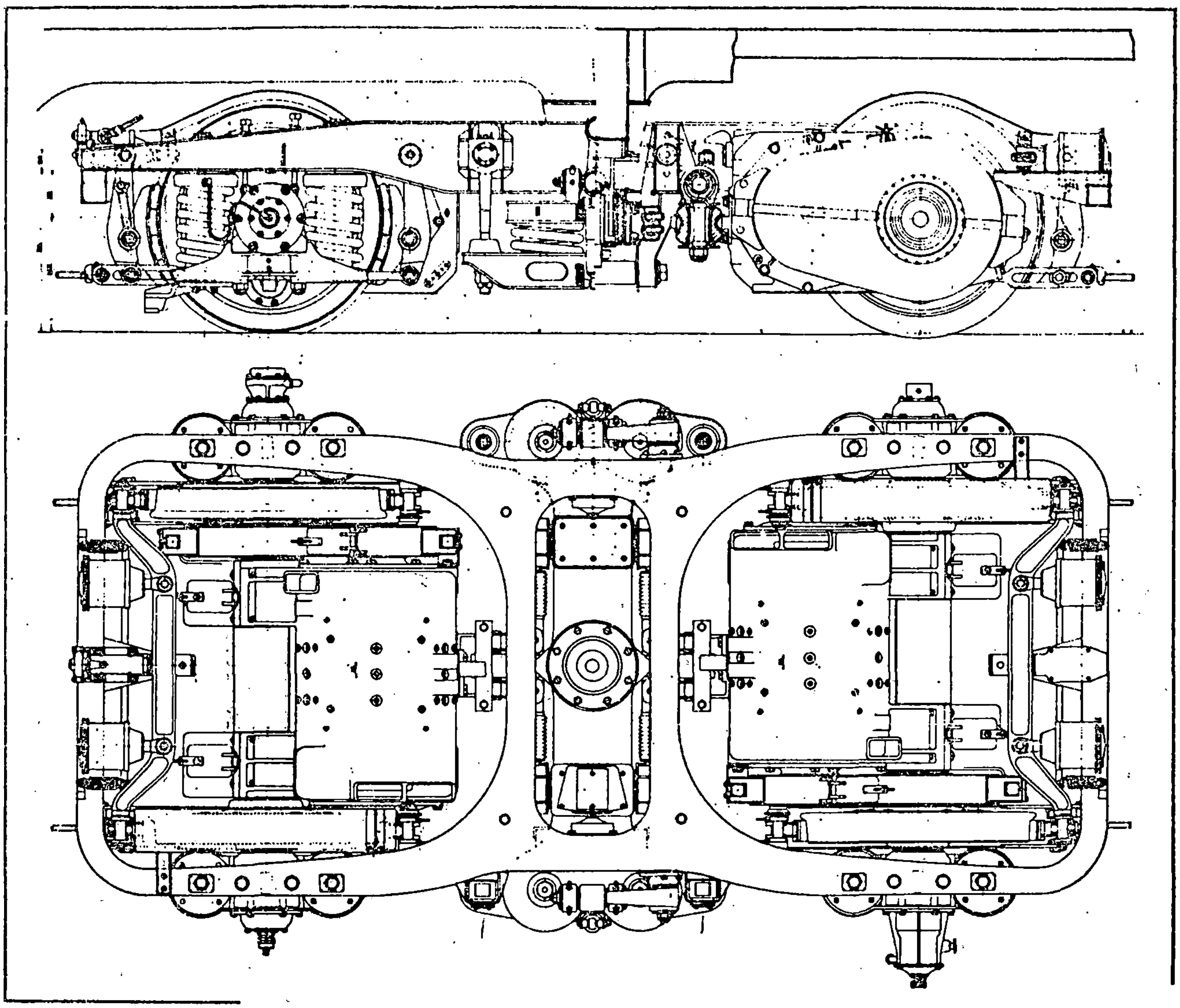

Truck frame
Center pin
Truck frame cross member
Slide pad
Bolster
Swing link for lateral secondary suspension
Wheel
Axle
Vertical secondary damper
Lateral secondary damper
Coil spring secondary vertical suspension
Spring plank
Primary vertical damper
Primary suspension

Figure 13

Z 1040



Courtesy of Rail Engineering International

Figure 14

German ET-403

The ET-403 is a 200 km/h four car electrically propelled train with all trucks powered.

The primary suspension is composed of four helical springs and four vertical hydraulic dampers. The longitudinal and lateral stiffnesses are provided by leaf links and elastic boxes. The longitudinal and lateral stiffnesses can be altered by changing the leaf links and the elastic boxes. Tests on the ET-403 will indicate the proper selection of the longitudinal and lateral stiffnesses for obtaining the most favorable conditions for 200 km/h stability.

The secondary suspension is made up of two M.A.N. air springs supported on laminated hollow rubber block springs which provide vertical and lateral stiffnesses and also allow rotation. After 15 mm air spring movement in negotiating curves, the air spring suspension is supplemented by elastic stops which are not shown. The secondary has two hydraulic shock absorbers for damping vertical motions, and one hydraulic shock for damping lateral and rotational motions by being located a distance from the lateral truck centerline. This truck is designed for body tilting of up to four degrees.

The vertical and lateral loads are transmitted from the carbody to the truck frame by the air springs, and then go out the primary suspension.

The longitudinal load goes through the center pin and the center pivot into the equalizer bar through the rubber bushed rods, and into the truck frame and out the primary suspension.

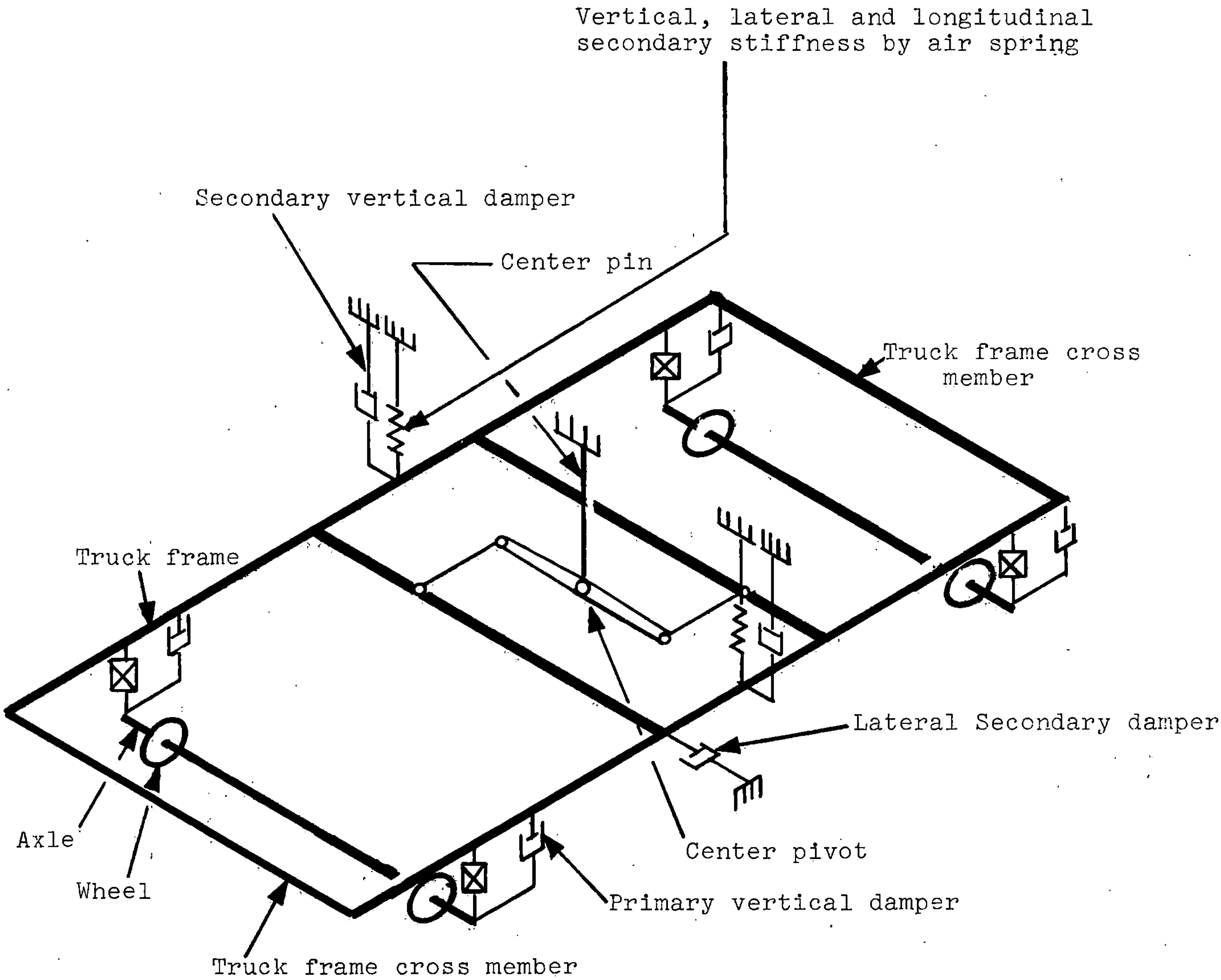
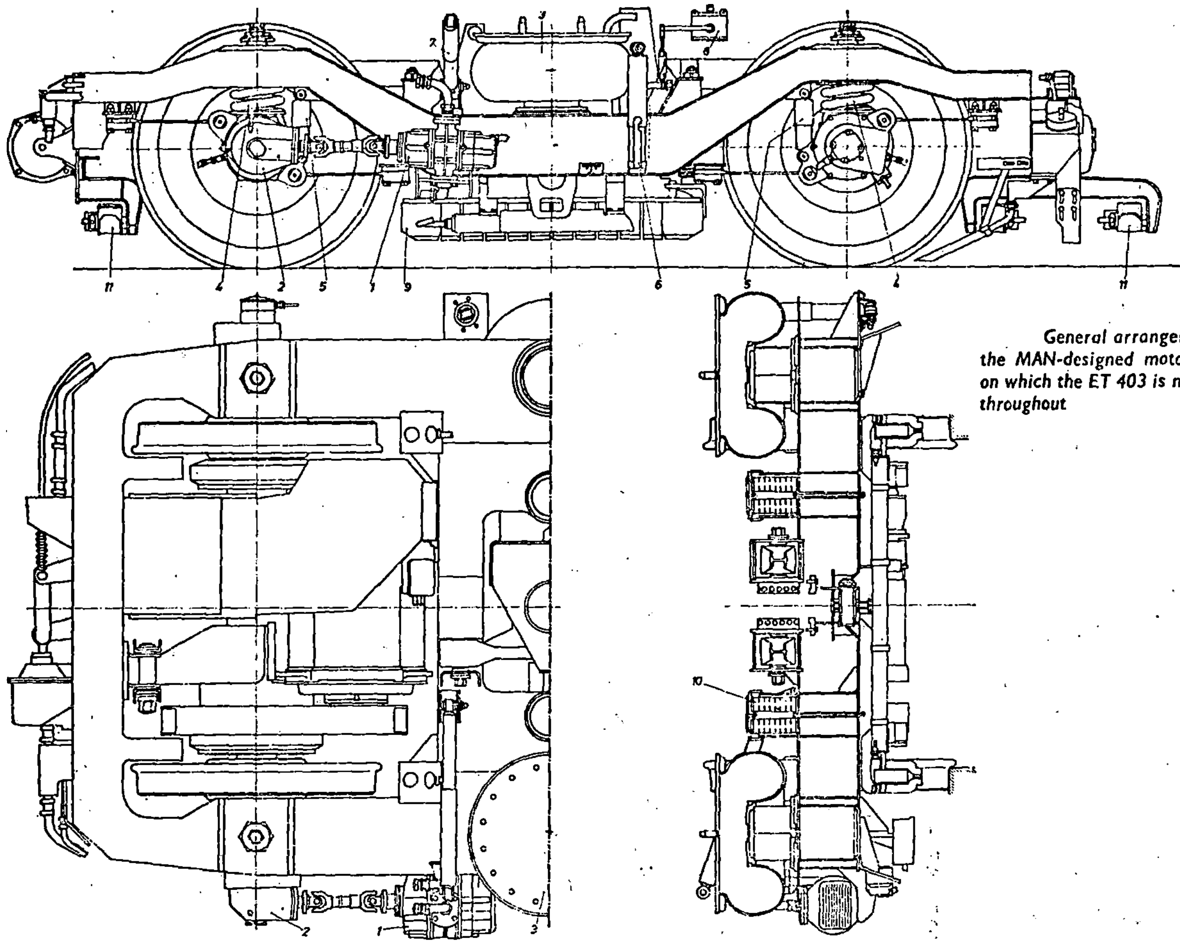

Vertical, lateral and longitudinal
secondary stiffness by air spring
Secondary vertical damper
Center pin
Truck frame cross
member
Truck frame
Lateral Secondary damper
Axle
Wheel
Center pivot
Primary vertical damper
Truck frame cross member

Figure 15

ET 403



Courtesy of Rail Engineering International

Figure 16

German Minden Deutz

This particular Minden Deutz truck is designed for 200 km/h or higher and was one of the four designs submitted for use as the European standard truck. The truck is a swing hanger type design.

The primary suspension is composed of eight helical coil springs for vertical motions, and eight leaf links for lateral and longitudinal motions. There are four hydraulic dampers for restricting vertical motions.

The secondary suspension comprises four helical coil springs mounted between the spring plank and the bolster only two are shown in the sketch. There are two vertical hydraulic dampers. The lateral stiffness comes from the swing links which is supplemented by rubber stops. These rubber stops are not shown in the sketch. There is one lateral damper located between the bolster and spring plank.

Rotational restraint consisting of link rods to guide the bolster and prevent it from moving longitudinally is an added feature of the truck. Also, the truck has a roll bar with spherical joints to allow free lateral motion of the bolster.

The vertical and lateral load is transmitted from the carbody through the center pin into the bolster down through the coiled spring secondary to the spring plank into the swing links. Then it goes through the truck frame and finally out through the primary suspension.

The longitudinal load is transmitted through the center pin into the bolster through the long link rods into the truck frame, and outthe primary suspension.

MINDEN DEUTZ

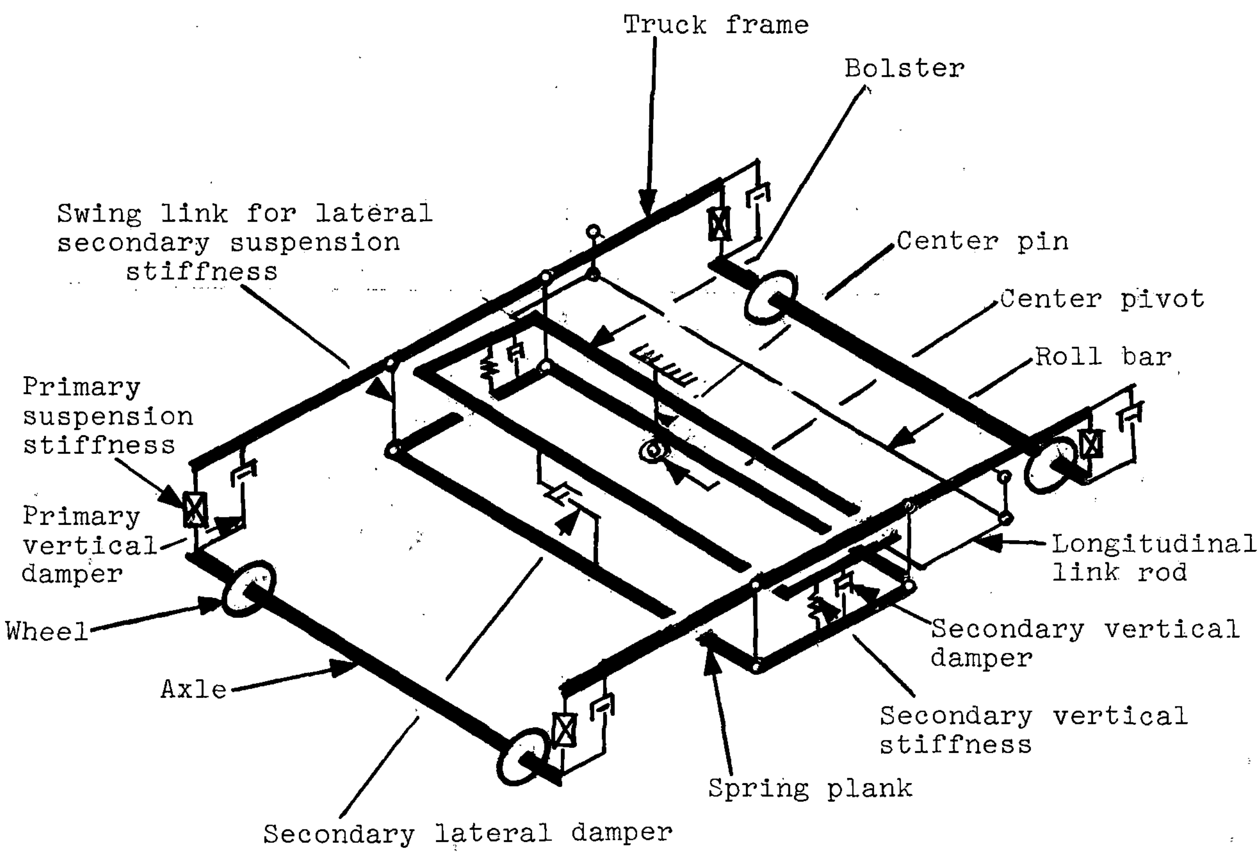
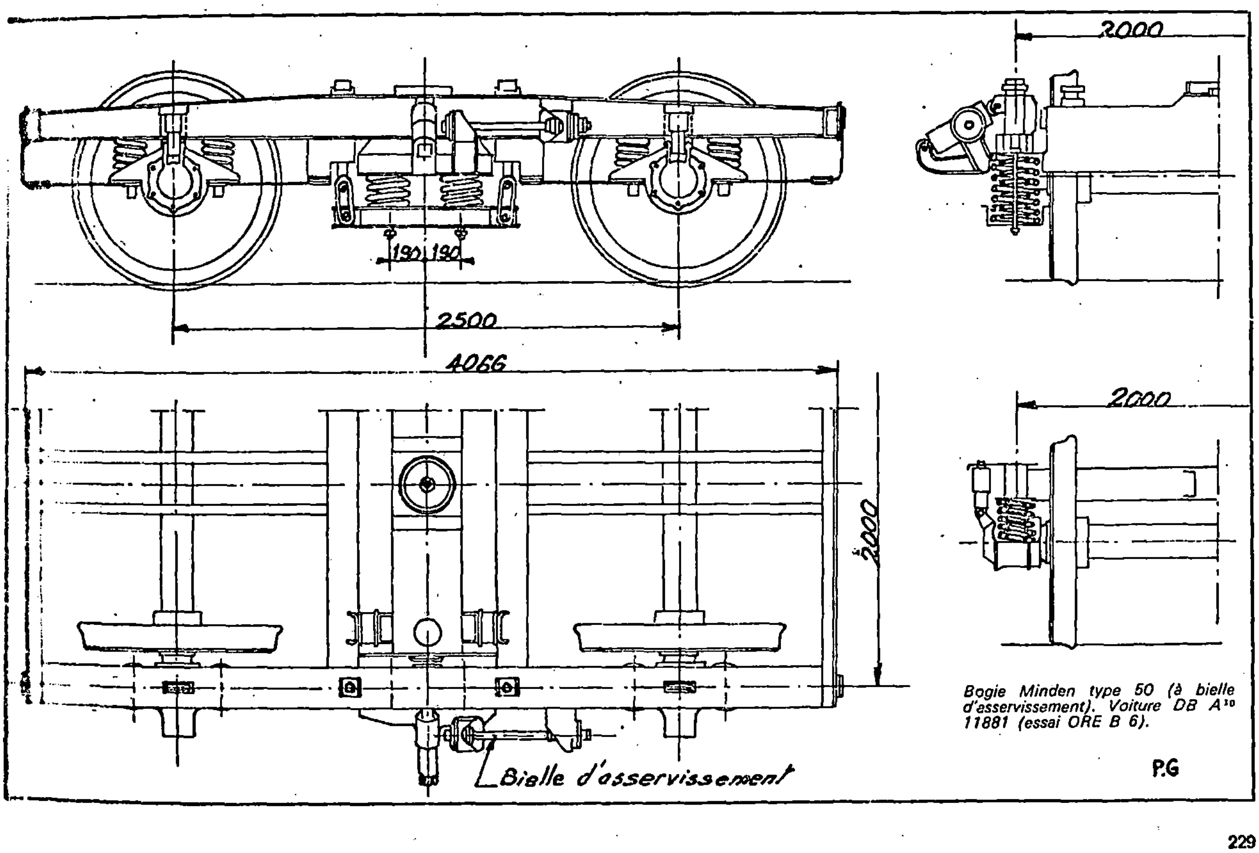


Figure 17

MINDEN DEUTZ



Courtesy of Chemins De Fer

Figure 18

JAPAN DT200

The DT200 is a truck which is used on the Japanese New Tokaido Line and is designed for speeds of 200 km/h between the cities of Tokyo and Osaka. The track is standard gauge 1435 mm or 56.5 inches.

The primary suspension is composed of eight helical coil springs for vertical movements, and eight leaf links, similar to the Minden Deutz truck, with rubber bushings at the end for lateral and longitudinal motions. This suspension system is represented in the sketch by four springs. Four vertical dampers restrict vertical motions.

The secondary suspension consists of two air springs which provide vertical and lateral stiffnesses, and also restrict vertical motions due to air damping. This vertical air damping is supplemented by two hydraulic dampers. There are two lateral hydraulic dampers in the secondary. The longitudinal stiffness comes from two anchor rods which connect the bolster to the carbody.

The vertical load is transmitted from the carbody through the air springs, into the side bearers and out the primary suspension.

The lateral load is transmitted through the air springs into the center pivot, and out the primary suspension.

The longitudinal load is transmitted from the car through the anchor rods into the center pivot, and out the primary suspension.

DT - 200

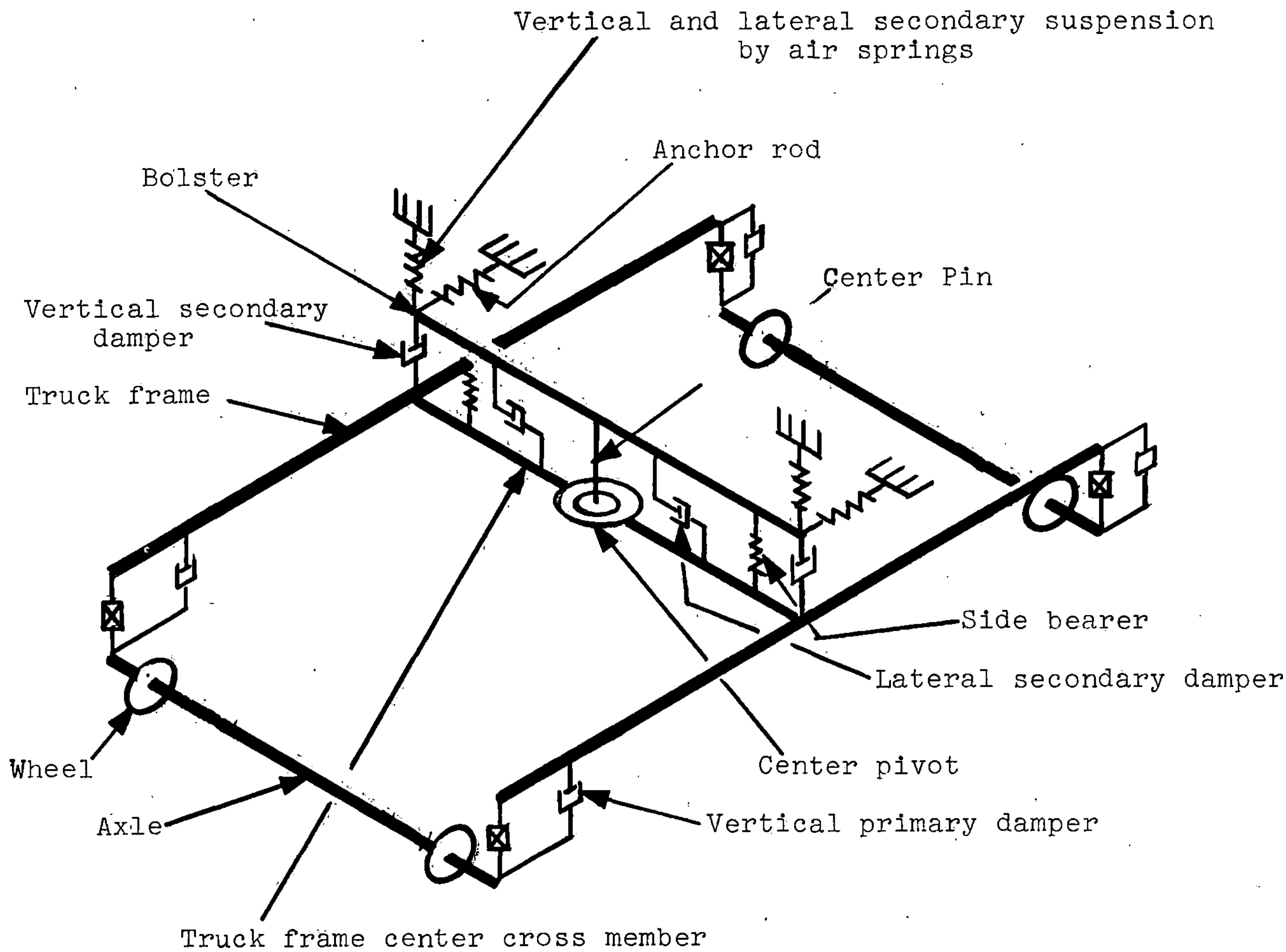
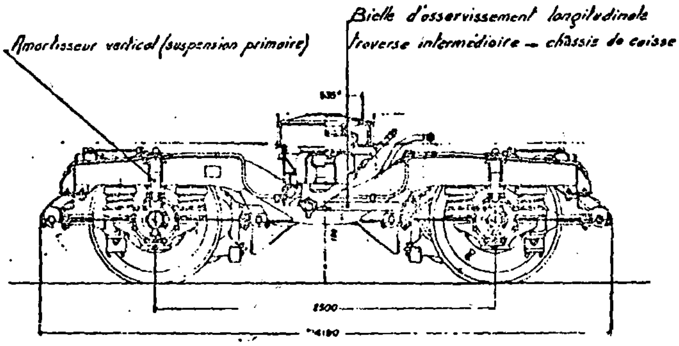
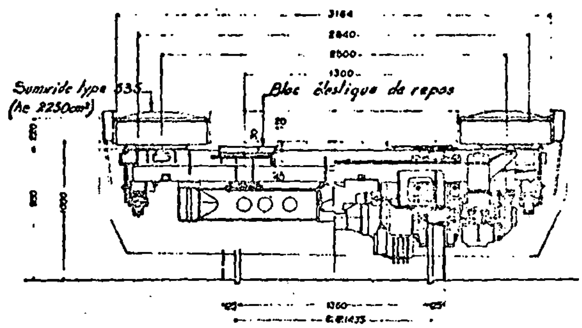


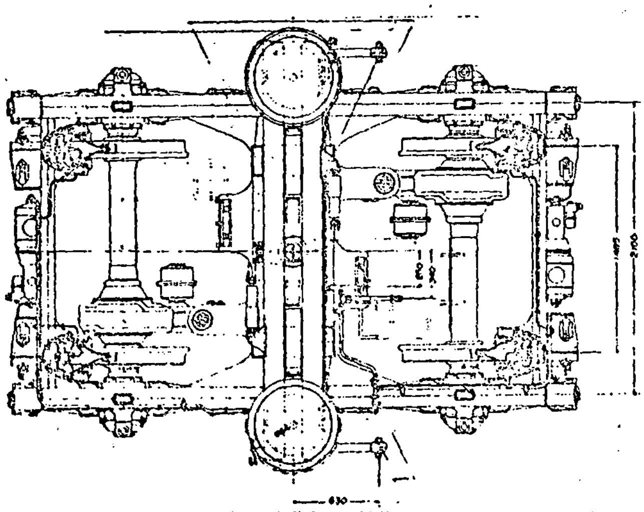
Figure 19

DT-200





Bogie-moteur JNR DT 200



Courtesy of Chemins De Fer

Figure 20

Canadian LRC

The LRC was tested at the U.S. Department of Transportation High Speed Ground Test Center at Pueblo, Colorado in the late autumn of 1974. Speeds of up to 210 km/h were reached.

The primary suspension of the LRC passenger car vehicle is composed of four Metalastik Chevron-springs which provide vertical, lateral and longitudinal stiffnesses. There are four Houdaille rotary hydraulic shock absorbers mounted at the axle boxes to control truck frame vertical and pitching motions.

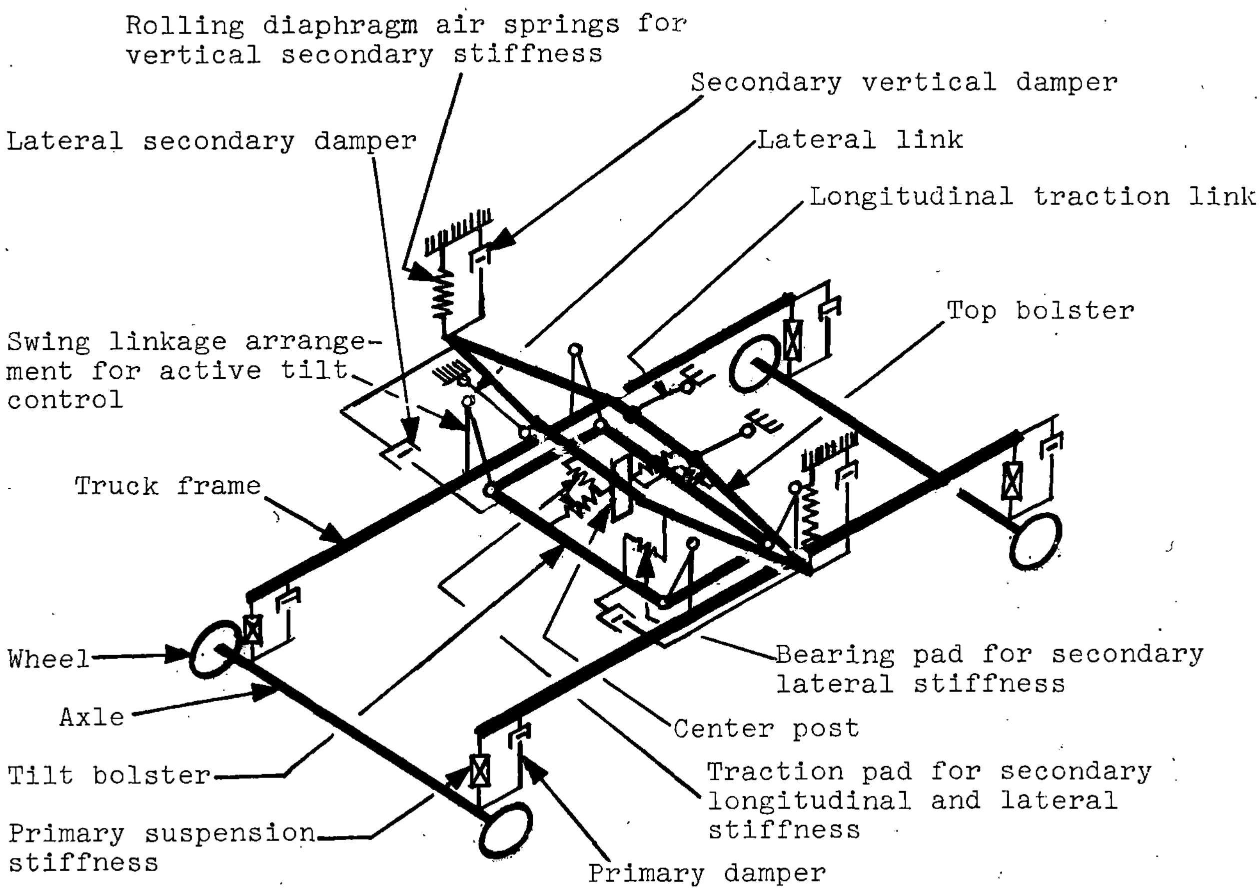
The secondary suspension has two large diameter rolling-diaphragm air springs for vertical and rotational motions. The lateral suspension is made up of the combined shearing of two traction and four bearing pads. The traction pads are located between the top bolster and the tilting bolster, and are contained between the top bolster and the center post. The center post is situated between the tilt bolster and the top bolster. The traction pads are represented in the sketch by two lateral suspension elements. The four bearing pads are located between the upper bolster and the tilt bolster and are represented in the sketch by one suspension element. There are two vertical and two lateral hydraulic dampers for restricting their respective motions.

The LRC truck is an interesting one due to the addition of an active tilt system. An accelerometer is mounted on the tilt bolster to sense lateral accelerations. When these accelerations become too high, the accelerometer signal causes the activation of the tilting mechanism, and the bolster tilts until the lateral acceleration falls below the detection threshold of the accelerometer.

The vertical load is transmitted through the air springs into the top bolster through the bearing pads to the tilt bolster out to the truck frame, and down the primary suspension.

The lateral load is transmitted from the carbody to the bolster through the lateral link into the traction and bearing pads to the tilt bolster. The load goes out to the truck side frames and through the primary suspension.

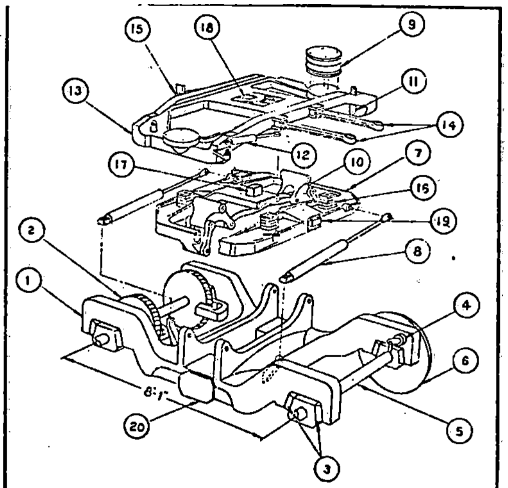
The longitudinal load is transmitted to the bolster through longitudinal traction links to the center post down to the tilt bolster out to the side frames and through the primary suspension.



Rolling diaphragm air springs for vertical secondary stiffness
Secondary vertical damper
Lateral secondary damper
Lateral link
Longitudinal traction link
Top bolster
Swing linkage arrangement for active tilt control
Truck frame
Wheel
Axle
Tilt bolster
Primary suspension stiffness
Bearing pad for secondary lateral stiffness
Center post
Traction pad for secondary longitudinal and lateral stiffness
Primary damper

Figure 21

L R C



1. FRAME
2. DISC BRAKES
3. CHEVRON SPRINGS
4. ROTARY DAMPERS
5. AXLE
6. WHEEL
7. TILTING BOLSTER
8. HYDRAULIC CYLINDER
9. AIR SPRING
10. SWING LINKAGE
11. VERTICAL DAMPERS
12. LATERAL DAMPERS
13. SPRING PLANK
14. TRACTION BARS
15. TRANSVERSE LOCATING LINK
16. BEARING PADS
17. CENTRE POST
18. TRACTION PADS
19. ACCELEROMETER
20. PREVENTER

Exploded view of the coach bogie

92

Courtesy of Rail Engineering International

Figure 22

English BT10

The BT10 truck is used on the British Rail's High Speed Train passenger coaches. This high speed diesel train was tested at a speed of 225 km/h in June of 1973 and is composed of two power cars and several intermediate passenger coaches.

The primary suspension consists of four helical springs for vertical stiffness. There are axle box radius arms which are pinned through rubber bushings to the frame and they provide the lateral and longitudinal stiffnesses. Four hydraulic dampers restrict the vertical motions between the frame and the axle.

The secondary suspension is composed of two diaphragm air springs for vertical motions. These are located between the spring plank and bolster. Four swing links which connect the truck frame to the spring plank provide the lateral stiffness. The longitudinal secondary stiffness comes from two anchor rods which are connected between the bolster and the truck frame. It should be noted that both the spring plank and bolster are represented in the sketch by an area. There are two truck frame cross members not indicated in the sketch.

The vertical load path is transmitted from the body through the slide pads into the bolster through the air springs up the swing links to the truck frame and then out the primary suspension.

The lateral load path is carried from the body through the center pin and the bolster. The load goes down the air springs to the spring plank up the swing links and then out the primary suspension.

The longitudinal load is transmitted through the center pin out to the sides of the bolster through the anchor rods to the truck frame and out the primary suspension.

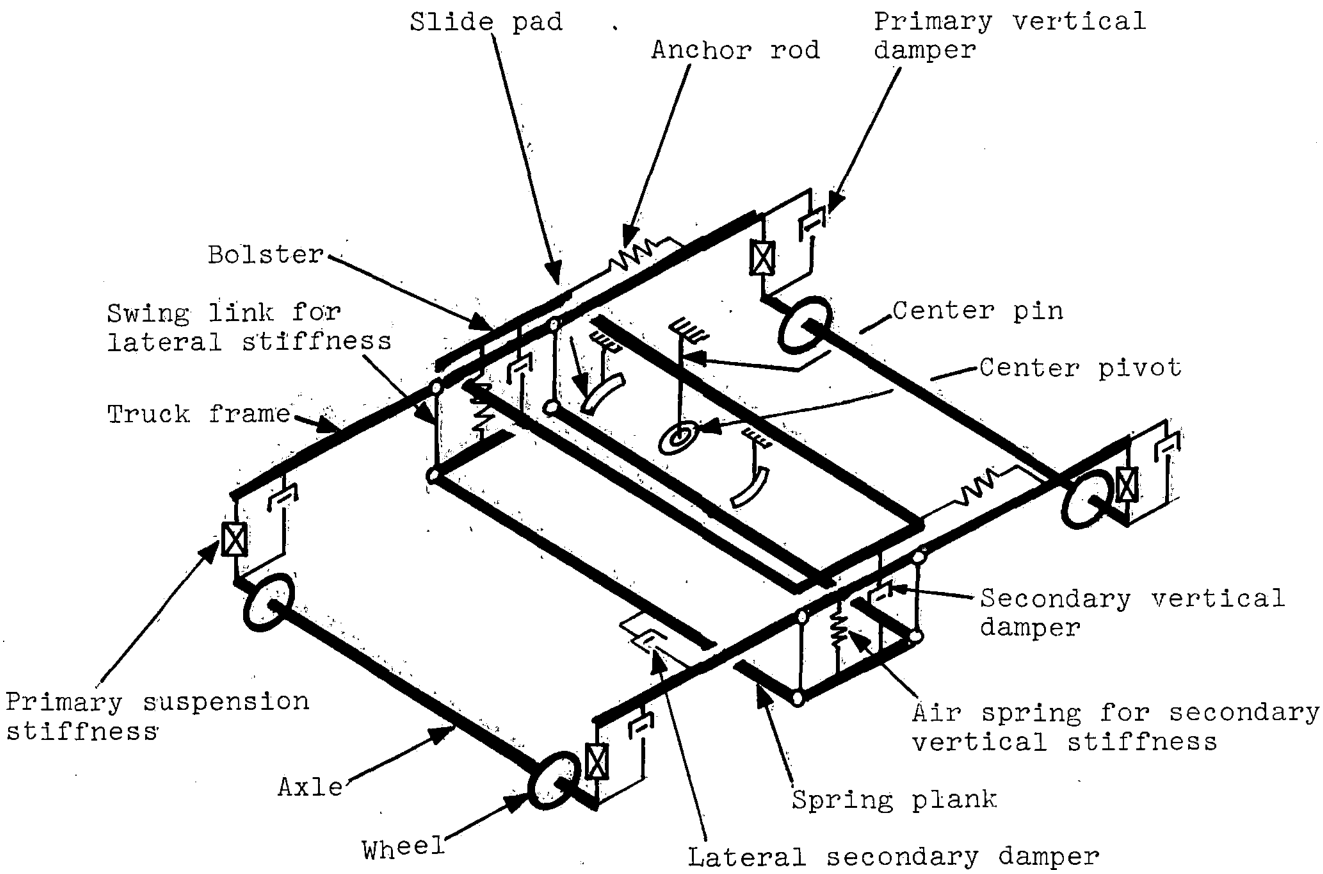
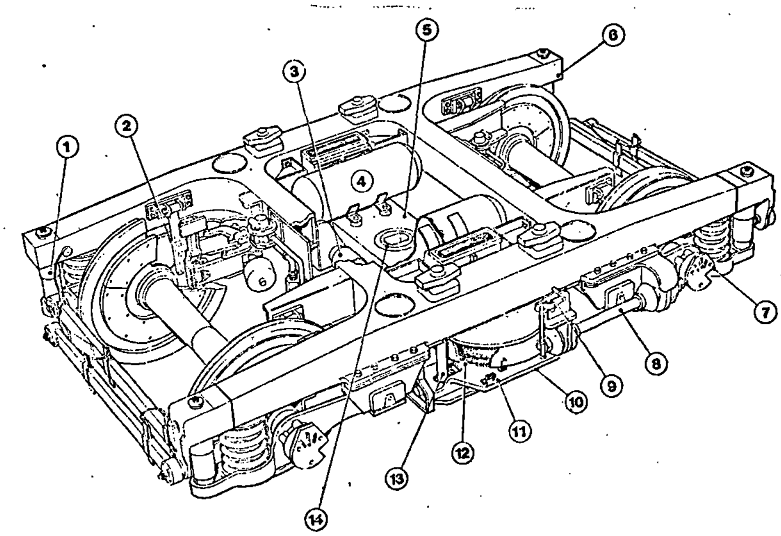

Slide pad
Anchor rod
Primary vertical damper
Bolster
Swing link for lateral stiffness
Truck frame
Center pin
Center pivot
Secondary vertical damper
Primary suspension stiffness
Axle
Wheel
Air spring for secondary vertical stiffness
Spring plank
Lateral secondary damper

Figure 23

BT-10

Fig. 2. *Isometric drawing of BR Mark III coach BT10 bogie as fitted to the intermediate vehicles of the HST*

1. *Primary damper*
2. *Disc brake*
3. *Lateral damper*
4. *Air reservoir*
5. *Bolster*
6. *Bogie frame*
7. *Wheel slide protection detector*
8. *Traction rod*
9. *Levelling valve*
10. *Spring plank*
11. *Air suspension indicator*
12. *Air spring*
13. *Swing link*
14. *Centre pivot*



Courtesy of Rail Engineering International

Figure 24

RUSSIAN ER200

The ER200, a 14-car train designed for 200 km/h service between Moscow and Leningrad had already achieved 206 km/h prior to June of 1975 on the Sherbinka test track near Moscow. The 14-car train has the trucks of the two end cars unpowered with all the remaining trucks powered. The same type truck is used under all cars. The track gauge is 1524 mm or 60 inches as opposed to the standard of 1435 mm and 56.5 inches.

The primary suspension of the ER200 has eight helical coil springs to provide vertical stiffness. There are flexible connections between the axle and the truck frame to provide vertical, lateral and longitudinal motions. There are four hydraulic shock absorbers for restricting vertical motions.

The secondary suspension consists of two self-levelling air springs to provide vertical and lateral stiffnesses. There are two vertical, and two lateral hydraulic dampers per truck. The anchor rods located between the bolster and carbody give the longitudinal secondary suspension stiffness.

The vertical load is transmitted from the carbody through the air springs, down the side bearers into the truck frame and out the primary suspension.

The lateral load goes from the carbody through the air springs, down the center pin to the pivot into the truck frame and out the primary suspension.

The longitudinal load goes from the carbody through anchor rods down the center pin into the truck frame and out the primary suspension.

ER 200

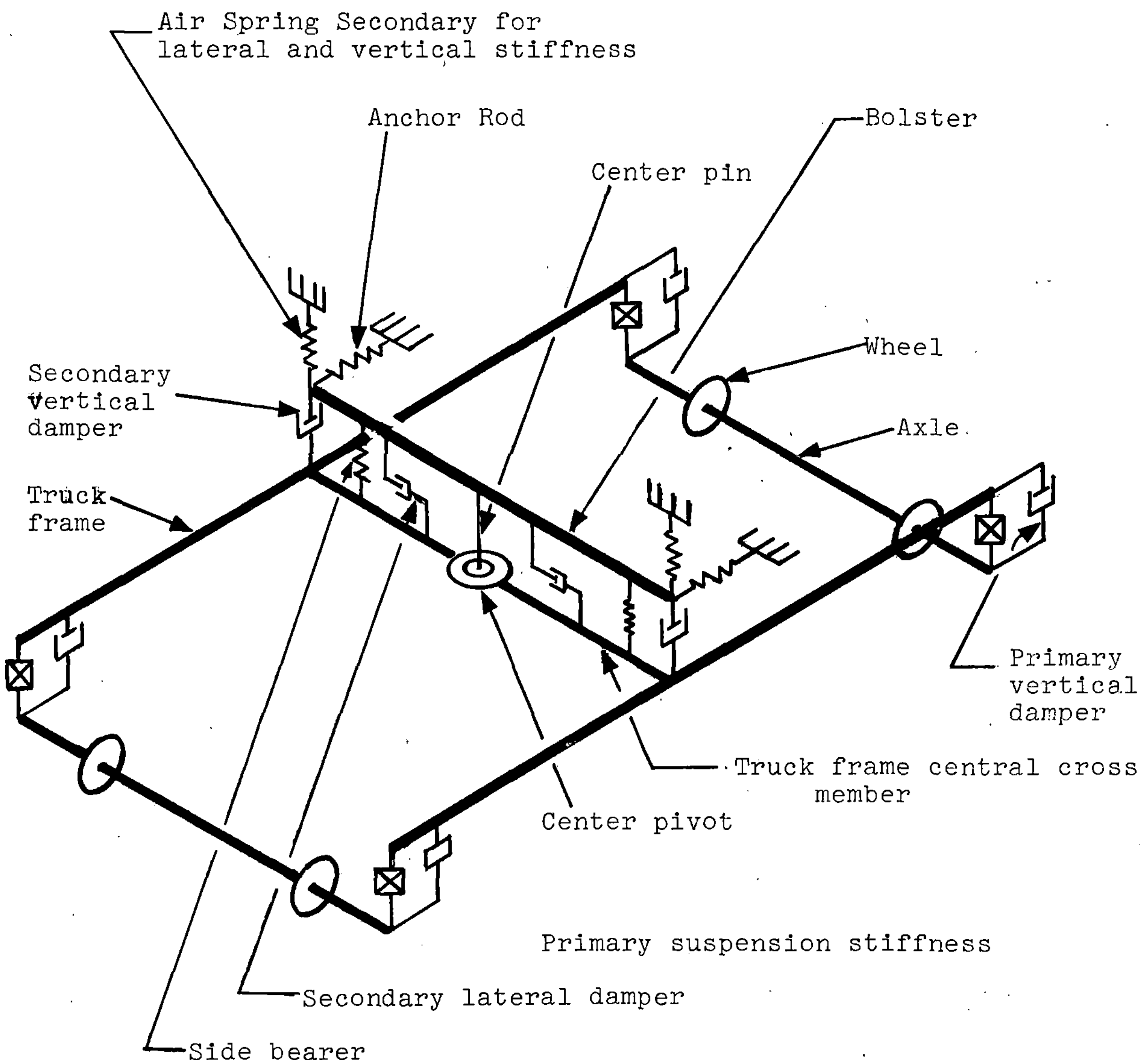
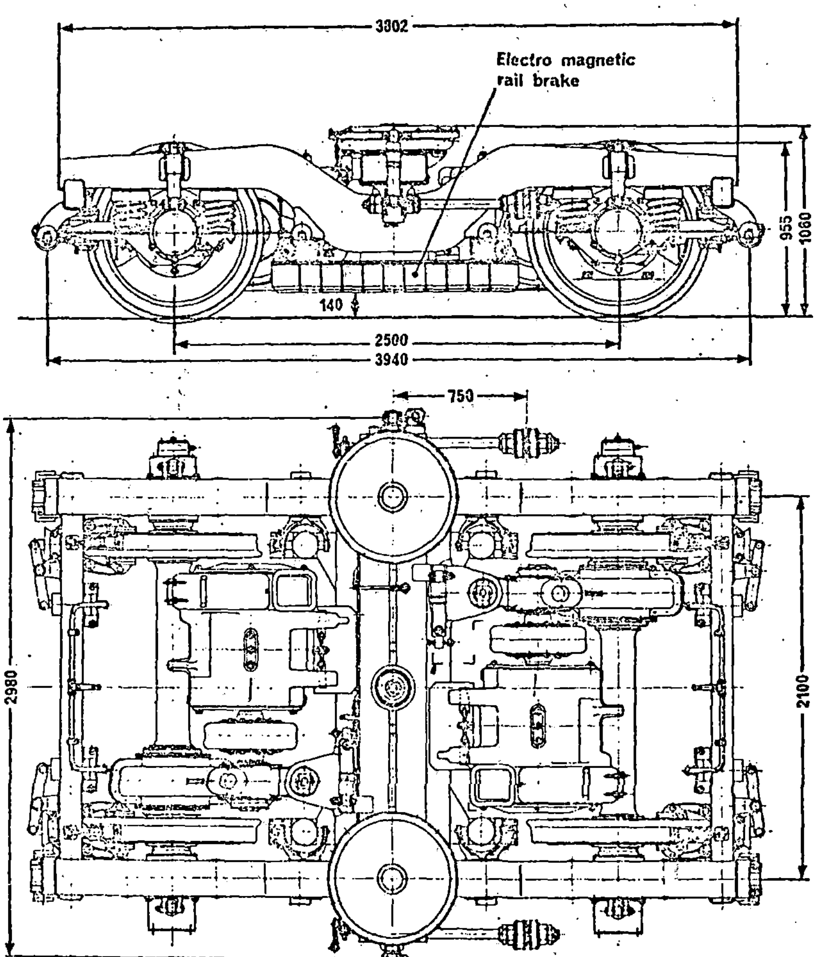


Figure 25

ER 200



Powered bogie for the ER200 with electro-magnetic rail brakes for emergency use only

Courtesy of Railway Gazette International

Figure 26

Pioneer - III

This particular version of the Pioneer - III truck was designed for use on the Amcoaches. The Amcoaches are locomotive hauled and capable of speeds up to 120 mph.

The P - III primary suspension consists of four rubber rings between the axle and the side frame and four side bearers between the side frames and the bolster. There are no hydraulic dampers in the primary. The primary suspension is relatively stiff in comparison to the other high speed trucks described.

The secondary vertical suspension consists of coil springs in series with air springs. The lateral stiffness is obtained by the shearing of the coil springs in series with lateral stabilizing rods having rubber bushings at the ends. There are two Houdaille rotary shock absorbers in both the vertical and lateral directions for restricting these motions. Two anchor rods connected between the bolster and carbody restrict longitudinal motions.

The P - III is an articulated frame with independent side frames.

The vertical load is transmitted from the carbody through the air and coil springs to the side bearers and out the primary suspension.

The lateral load goes from the carbody through the coil and stabilizing rods through the center pivot to the truck frame and out the primary suspension.

The longitudinal load goes from the carbody through the anchor rods into the center pivot to the truck frame and out the primary suspension.

P - III

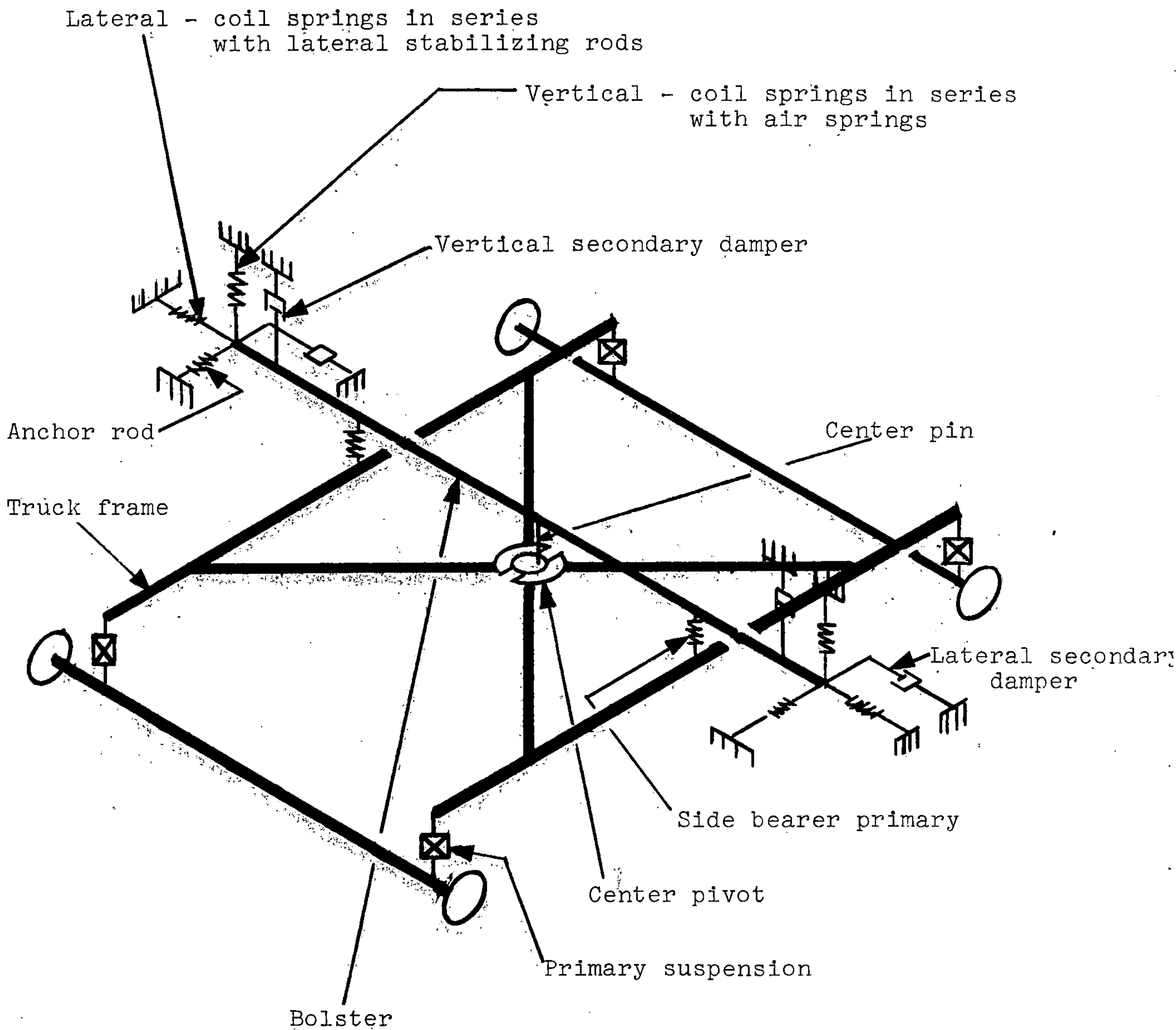
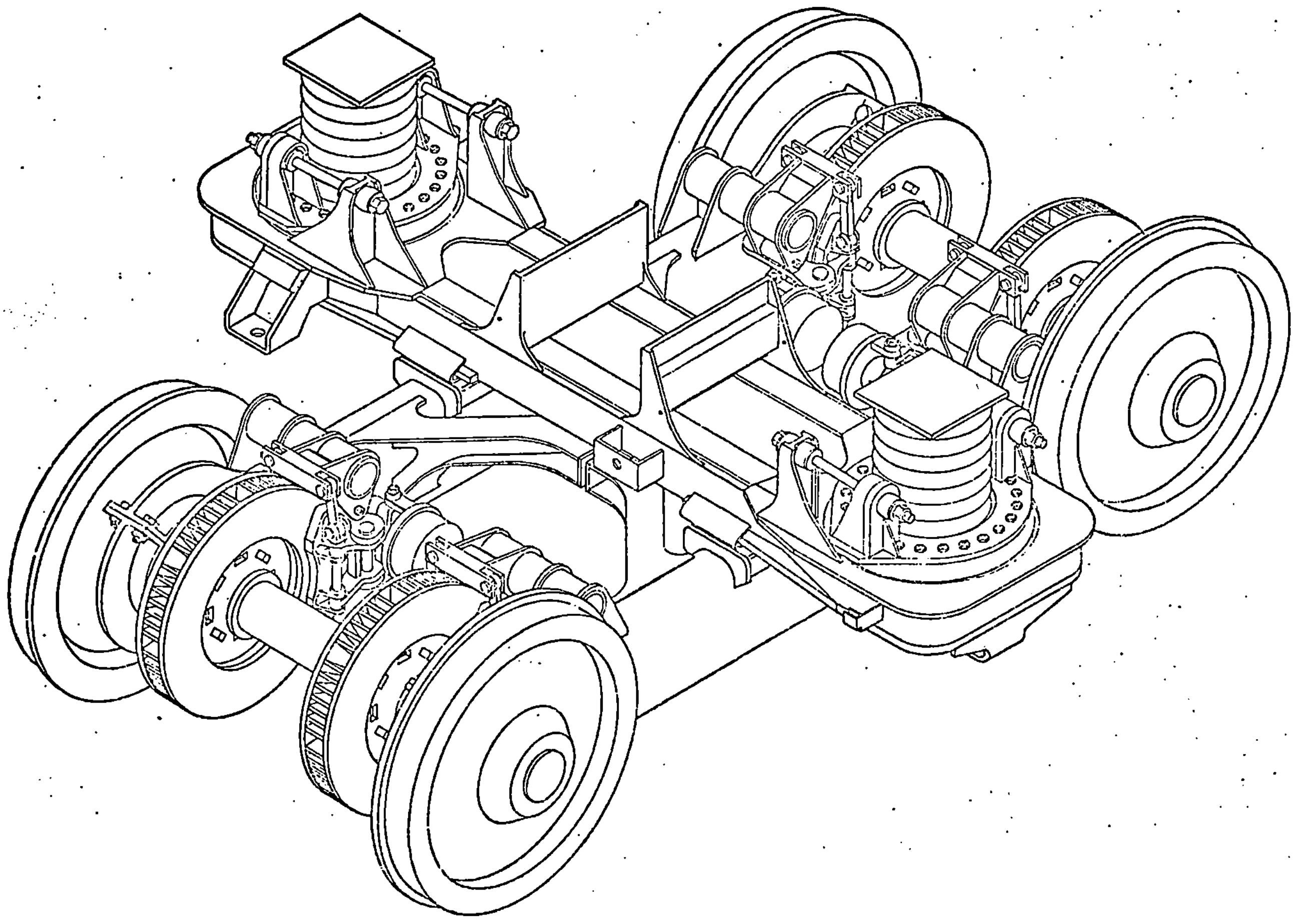


Figure 27

P-III



TRUCK ARRANGEMENT

Figure 28

METROLINER

The Metroliner is a vehicle designed for speeds of 160 mph or 258 kmh. There are 61 of these vehicles in service in the Northeast Corridor. Both axles of the Metroliner truck are powered.

The primary suspension consists of an equalizer beam with Pirelli coil springs mounted on it, which provide vertical, lateral and longitudinal suspension stiffness.

The secondary suspension is composed of coil springs in parallel with air springs to give vertical and lateral suspension stiffnesses. The air springs are designed to provide load leveling of the carbody under the passenger load and does not add much stiffness to the coil spring. Anchor rods connected between the bolster and carbody give the longitudinal stiffness. Secondary damping is achieved by two vertical rotary dampers and two lateral rotary dampers.

The Metroliner has a 12500 pound power transformer suspended from the carbody which adds complexity to the dynamic system.

The vertical and lateral loads are transmitted from the carbody through the air and coil springs into the bolster to the center pin down to the central cross member out to the truck frame down the primary suspension and then out the equalizer beam.

The longitudinal load goes from the carbody through the anchor rods to the bolster over to the center pin back out over to the cross member to the truck side frame through the primary suspension and out the equalizer beam.

METROLINER

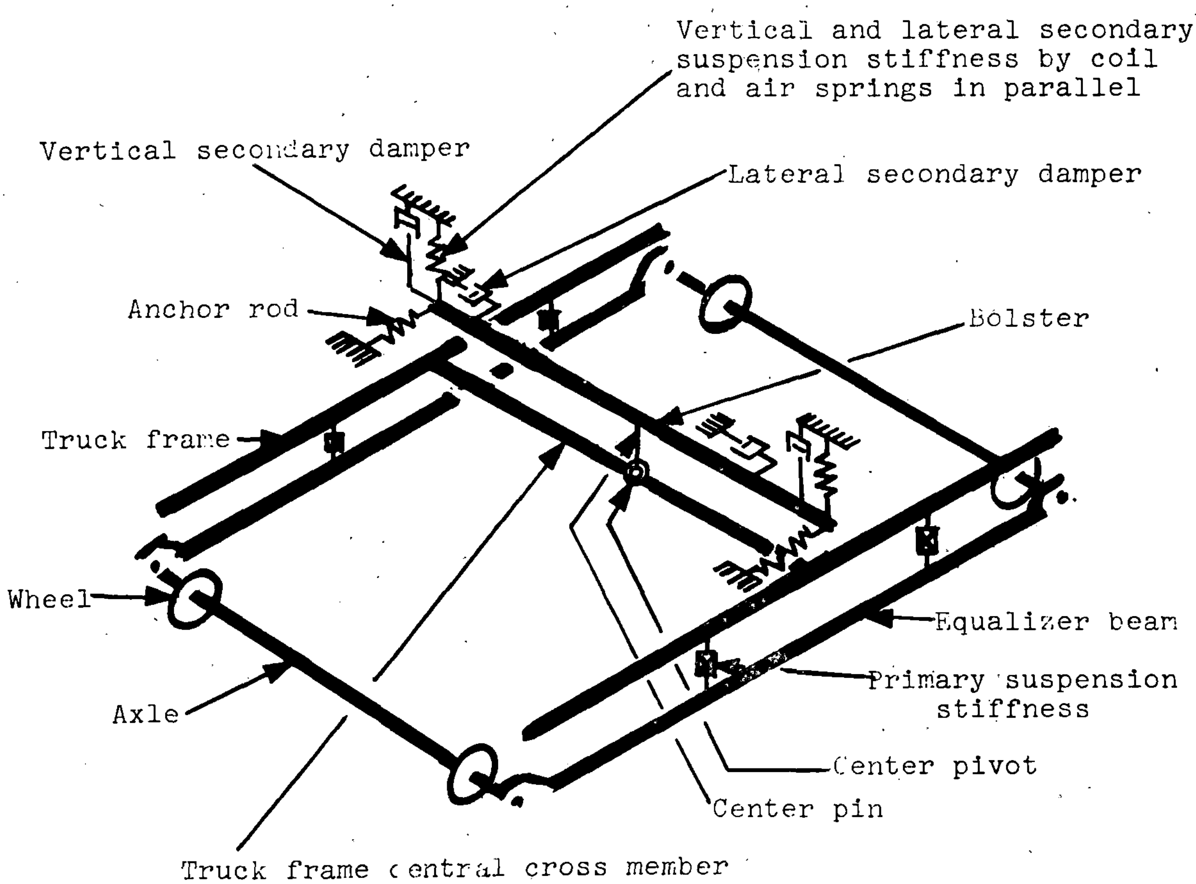


Figure 29

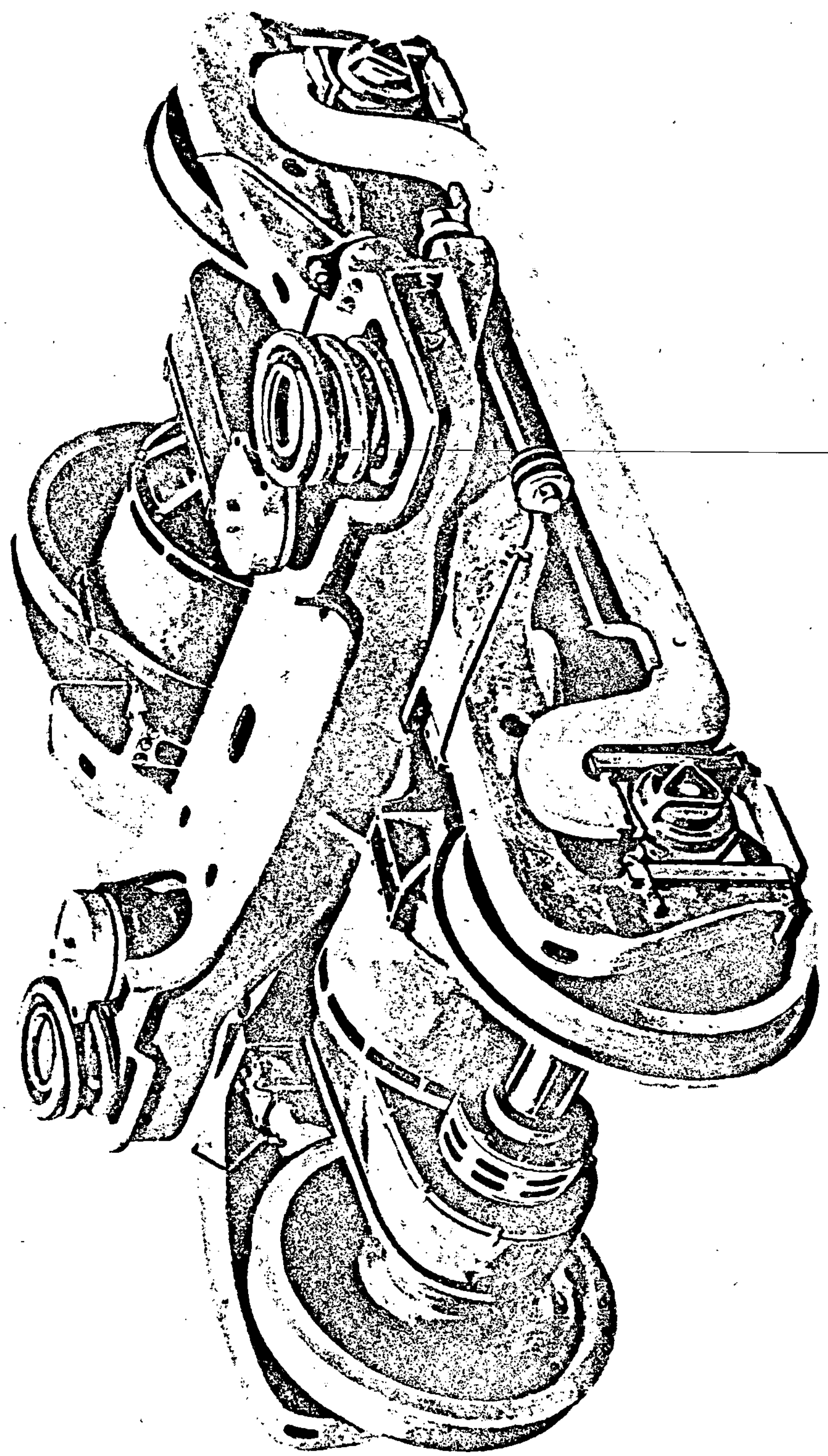


Figure 30

4.2 Truck Data

The data for each high speed truck mentioned in section 2.2 is included here in a table with a common engineering format. Basic properties or characteristics of the trucks are given at the top of each page such as the truck type, total truck weight per vehicle, car body ready to run weight and the design speed. The units are specified in both the English System and in parenthesis for the Metric System.

The data presented are limited in scope being based upon data which were available and retrievable from The Budd Company's files. Engineering estimations supplied in the tables are based on The Budd Company's experience in the railcar industry.

The table itself is broken down into three main sections; the truck unsprung mass, the truck sprung mass and the truck suspension characteristics. All the basic parameters essential for dynamic modeling activities are provided in this table. An NA in the table means the data is not applicable.

The engineering format developed is based on the truck being symmetrical about its axis, so there are no offset distances to be considered. The truck frame and bolster center of gravity are located at their geometric center.

4.2.1 Truck Unsprung Mass Discussion

In the Truck Unsprung Mass Section of the table the following methods were employed where engineering estimations were required:

1) Wheelset mass approximations were based on the wheel diameter and on other truck wheelsets where masses were known.

2) The total truck unsprung mass was estimated to be twice the wheelset mass, except for the LRC and the ER 200 where the estimations of truck unsprung mass were chosen so that the ratio of truck sprung to unsprung mass was in the same range as the ratios for the other unpowered and powered trucks, respectively.

4.2.2 Truck Sprung Mass Discussion

The mass estimations in the truck sprung mass section of the table were calculated based on the estimation for unsprung mass and then doing the necessary subtractions since the total truck mass was always known.

The roll pitch and yaw radii of gyration calculations for all trucks were based on one-third of the sprung weight at each side frame and one-third in the middle section.

The column for traction motor mass includes one of the following three items:

a) Unpowered, mass not applicable

b) Powered, but mass unknown

c) An actual mass number

In the tables where b) and c) are applicable either an NI or I is used to explain whether the traction motor mass has been included in the truck sprung. An NI indicates the mass has not been included, and an I indicates the mass has been included.

The electromagnetic brake mass is not included in the sprung mass of trucks Y-28, Y-32, Fiat Eurofa, Minden Deutz, and ER200. This is represented in the table by an NI adjacent to the mass number of the E.M. brake. In these trucks, the brake is sprung from the truck frame at an estimated frequency of less than 5 Hz. This would effect the low frequency dynamics for soft primary suspension trucks.

The electromagnetic brake mass is included in trucks Y-224, Y-225, Y-226 and ET-403; and this is represented in the data table by an I adjacent to the mass number for the brake. In these trucks the E. M. brake is controlled by a pneumatic system and unless the E. M. brakes are applied, the mass is considered to be part of the sprung mass of the truck.

When estimations of the E.M. brake masses were needed, they were made based on other truck E.M. brakes where masses were known.

4.2.3 Truck Suspension Discussion

In the truck suspension section of the table, the stiffness and damping numbers are on a per truck basis. The vertical distance from the top of the running rail (TORR) to the springs and dampers are distances to their effective points of action, usually at the geometric center.

The following methods were used when engineering estimations were needed:

1) The range of lateral and longitudinal primary suspension stiffnesses were based on a single degree-of-freedom approach for the truck rigid body mode where frequencies varied from a lower limit of 4 Hz to an upper limit of 100 Hz.

2) The lateral and longitudinal primary damping assumed a range of critical damping from 2% to 50% considering the truck rigid body mode.

3) The range of longitudinal secondary suspension stiffness varied from 3 Hz to 50 Hz for the rigid car body modes.

4) The longitudinal secondary damping ranged from 2% to 50% of critical damping for the rigid car body modes.

5) A range of vertical primary suspension damping was provided. The upper limit of the vertical uncoupled sprung truck mass bounce mode was damped at 50% of critical damping. The lower limit of the primary damping was based on a total weight (1/2 car and sprung truck) resting on the primary suspension of a truck, that the vibration would be damped at 2% of critical damping.

6) The vertical secondary damping was estimated based on 17% of critical damping of the carbody vertical bounce mode and the effects due to the primary suspension.

7) The secondary lateral damping was estimated based on a range between 10% and 30% of critical damping of the carbody uncoupled lateral rigid body mode.

In instances where the primary and secondary suspension stiffnesses were not available from the literature, the stiffnesses were calculated based on a 1.1 Hz uncoupled carbody bounce frequency and 5.5 Hz coupled vertical carbody and truck bounce modes, except in cases of the Y-224 truck, and the Minden Deutz truck.

The Y-224 stiffnesses were based on coupled carbody and truck modes having a low frequency of 1.35 Hz and a high frequency of 7.35 Hz.

The Minden Deutz primary vertical suspension was based on an article from the literature, but it was uncertain whether the information was directly applicable to this truck. The secondary vertical stiffness assumed a 1.1 Hz uncoupled car body bounce frequency.

The lateral secondary suspension stiffness estimations were based on an uncoupled lateral rigid carbody mode having a frequency of .7 Hz. The .7 Hz frequency number was used due to the experience obtained from known trucks. The ET 403 is an exception to this: the estimation was based on an article from the literature where the suspension was said to be slightly stiffer than another truck where the data was known. The value of slightly stiffer was selected to be 10% greater than the known truck.

The part of the truck suspension section of the table having to do with roll stiffness and damping, and yaw stiffness and damping has numbers supplied only when a truck has a particular device for adding to the stiffness or damping in these degrees of freedom. For example, if a truck has a roll bar, this would provide additional roll stiffness, than that provided by other suspension elements.

The Y-28 and Y-32 roll bar stiffnesses were calculated based on coupled roll lateral frequencies. The Fiat Eurofa truck and the minden Deutz roll stiffnesses were estimated based on their similarity to the Y-32.

Yaw frictional restraint numbers were calculated for all trucks based on the following article by j. L. Koffman entitled "Rotational Resistance of Bogie Wagons" from Rail Engineering International, July, 1971, pages 106 to 112.

Yaw damping estimations were made only on those trucks which had a device which included a shock absorber for restricting only yaw motion. These trucks are the Y-32, Y-225 and Fiat Eurofa. The estimations were based on converting the range of yaw frictional restraint into viscous damping numbers.

Truck data table abbreviations:

NA - data is not applicable

NI - mass is not included in truck sprung mass

I - mass is included in truck sprung mass

* - engineering estimation

Truck Type: French Y-28
Car Body: See Table 17
Truck Weight (2 Trucks): 26460 lbs. (12t)
Car Body RTR Weight: 83790 lbs. (38t)
Vehicle RTR Weight: 110250 lbs. (48.8t)
Design Speed: 125 mph (200 kmh)

TRUCK UNSPRUNG MASS

	Mass $Lb\text{-}Sec^2/In$ $(Kg\text{-}Sec^2/Cm)$	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	7.3* (1.31*)	36.2 (920)	1/40*-.3*	100.8 (2560)	56.5 (1435)
Total Truck Unsprung	14.6 (2.62)				

TRUCK SPRUNG MASS

	Mass $Lb\text{-}Sec^2/In$ $(Kg\text{-}Sec^2/Cm)$ Per Truck	Radii of Gyration In. (mm)			TORR to Truck c.g. In (mm)
		Roll	Pitch	Yaw	
Truck Sprung	13.8 (2.46)	34.6* (879)*	29.1* (739)*	45.1* (1146)*	25.6 (650)
Bolster	2.4 (.42)	22.5* (572)*	7* (178)*	23.5* (597)*	34.6 (880)
Truck and Bolster Sprung	16.2 (2.88)	33.1* (842)*	27.1* (689)*	42.5* (1080)*	26.8 (680)
Traction Motor	Unpowered				
E.M. Brake	3.4 (.61) NI				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (kg-Sec/Cm) Per Truck	Spring Spacings In (mm)			Damper Spacings In (mm)		
				Vertical From TORR	Lateral	Long.	Vertical From TORR	Lateral	Long.
PRIMARY	Vertical	13150 (2347)	52*-125* (11*-27*)	NA	77.6 (1970)	100.8 (2560)	NA	77.6 (1970)	100.8 (2560)
	Lateral	112000-168000 (2000-3000)	18*-1650* (3*-295*)	18.1 (460)	NA	64.2 (1630)	18.1 (460)	NA	64.2 (1630)
	Long.	560000 (100000)	120*-3012* (21*-538*)	18.1 (460)	77.6 (1970)	NA	18.1 (460)	77.6 (1970)	NA
SECONDARY	Vertical	5186 (926)	420* (91*)	NA	74.0 (1880)	19.1 (485)	NA	54.4 (1380)	54.4 (1380)
	Lateral	2130 (380)	96*-288* (20*-62*)	25.6 (650)	NA	0.	25.6 (650)	NA	0.
	Long.	$38500\text{-}10.7 \times 10^{6}$* $(6900\text{-}1.9 \times 10^{6}$*)	82*-34000* (15*-6080*)	25.6 (650)	0 (0)	NA	25.6 (650)	0 (0)	NA

	Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
Roll	4.2×10^6 (4.8×10^6)	NA	NA
Yaw	NA	NA	1×10^{5}* to 5×10^{5}* $(1.2 \times 10^{5}$* to 6×10^{5}*)

Truck Type: French Y-32
Car Body: See Table 17
Truck Weight (2 Trucks): 30000 lbs. (13.6t)
Car Body RTR Weight: 70340 lbs. (31.9t)
Vehicle RTR Weight: 100340 lbs. (45.5t)
Design Speed: 155 mph (250 kmh)

Y - 32

Table 3

TRUCK UNSPRUNG MASS

	Mass Lb-Sec²/In (Kg-Sec²/Cm)	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	8.0 (1.43)	35.0 (890)	1/40*-.3*	100.8 (2560)	56.5 (1435)
Total Truck Unsprung	16.0 (2.85)				

TRUCK SPRUNG MASS

	Mass Lb-Sec²/In (Kg-Sec²/Cm) Per Truck	Radii of Gyration In. (mm) Roll	Radii of Gyration In. (mm) Pitch	Radii of Gyration In. (mm) Yaw	TORR to Truck c.g. In (mm)
Truck Sprung	19.4* (3.46)*	35.0* (889)*	29.0* (737)*	45.3* (1151)*	19.7 (500)
Bolster	NA	NA	NA	NA	NA
Truck and Bolster Sprung	NA	NA	NA	NA	NA
Traction Motor	Unpowered				
E.M. Brake	3.6 (.64) NI				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec/Cm) Per Truck	Spring Spacings In (mm) Vertical From TORR	Spring Spacings In (mm) Lateral	Spring Spacings In (mm) Long.	Damper Spacings In (mm) Vertical From TORR	Damper Spacings In (mm) Lateral	Damper Spacings In (mm) Long.
PRIMARY	Vertical	14000 (2500)	50*-266* (9*-47*)	NA	78.7 (2000)	100.8 (2560)	NA	78.7 (2000)	120.6 (3064)
PRIMARY	Lateral	26600 (4750)	29*-718* (5*-128*)	18.1 (460)	NA	66.9 (1700)	17.5 (444)	NA	66.9 (1700)
PRIMARY	Long.	324800 (58000)	100*-2510* (18*-448*)	18.1 (460)	78.7 (2000)	NA	18.1 (460)	78.7 (2000)	NA
SECONDARY	Vertical	4590 (820)	335* (60*)	NA	78.7 (2000)	0.	NA	106.3 (2700)	23.0 (585)
SECONDARY	Lateral	1867 to 1930 333 to 345	83*-250* (18*-54*)	28.4 (721)	NA	0.	32.2 (818)	NA	0 (0)
SECONDARY	Long.	32300-9x10⁵* (5770-1.6x10⁶)*	69*-28600* (12*-5100*)	17.5 (444)	0 (0)	NA	17.5 (444)	0 (0)	NA

SECONDARY		Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
SECONDARY	Roll	$2.5 x 10^6$ $(2.9 x 10^6)$	NA	NA
SECONDARY	Yaw	NA	$1.6-8.1 x 10^6$* $(1.8-9.3 x 10^6$*	$1 x 10^5$* to $5 x 10^5$* $(1.2 x 10^5$ to $6 x 10^5$*)

Truck Type: French Y224
Car Body: See Table 17
Truck Weight (2 Trucks): 28800 lbs. (13.06t)
Car Body RTR Weight: 65490 lbs. (29.7t)
Vehicle RTR Weight: 94290 lbs. (42.7t)
Design Speed: 125 - 155 mph (200 - 250 kmh)

Y - 224

Table 4

TRUCK UNSPRUNG MASS

	Mass $Lb\text{-}Sec^2/In$ ($Kg\text{-}Sec^2/Cm$)	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	8.0* (1.5*)	33.9 (860)	1/40*-.3*	106.3 (2700)	56.5 (1435)
Total Truck Unsprung	16.0* (2.86*)				

TRUCK SPRUNG MASS

	Mass $Lb\text{-}Sec^2/In$ ($Kg\text{-}Sec^2/Cm$) Per Truck	Radii of Gyration In. (mm)			TORR to Truck c.g. In (mm)
		Roll	Pitch	Yaw	
Truck Sprung	21.2* (3.79)*	36.7* (932)*	30.6* (777)*	47.6* (1209)*	18.1 (460)
Bolster	NA	NA	NA	NA	NA
Truck and Bolster Sprung	NA	NA	NA	NA	NA
Traction Motor	Unpowered				
E.M. Brake	3.4* (.61*) I				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec/Cm) Per Truck	Spring Spacings In (mm)			Damper Spacings In (mm)		
				Vertical From TORR	Lateral	Long.	Vertical From TORR	Lateral	Long.
PRIMARY	Vertical	37300* (6660)*	85*-619* (19*-134)	NA	82.1 (2085)	106.3 (2700)	NA	82.1 (2085)	106.3 (2700)
PRIMARY	Lateral	$13390\text{-}8 \times 10^6$ ($2391\text{-}1.4 \times 10^6$)*	21*-13000* (4*-2300*)	16.5 (420)	NA	106.3 (2700)	17 (430)	NA	106.3 (2700)
PRIMARY	Long.	$13390\text{-}8 \times 10^6$* ($2391\text{-}1.4 \times 10^6$)*	21*-13000* (4*-2300*)	16.5 (420)	82.1 (2085)	NA	17 (430)	82.1 (2085)	NA
SECONDARY	Vertical	7500* (1339)*	356* (64)*	NA	82.1 (2085)	0.	NA	82.1 (2085)	24.8 (630)
SECONDARY	Lateral	1650* (295)*	150* (27)*	40.2 (1020)	NA	0.	40.2 (1020)	NA	18.7 (475)
SECONDARY	Long.	$30100\text{-}8.4 \times 10^6$* ($5370\text{-}2.7 \times 10^6$)*	64*-26700* (11*-4800)*	40.2 (1020)	0.	NA	40.2 (1020)	106.3 (2700)	NA

SECONDARY		Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
	Roll	NA	NA	NA
	Yaw	NA	NA	1×10^5* to 5×10^5* (1.2×10^5* to 6×10^5)*

Truck Type: French Y-225
Car Body: See Table 17
Truck Weight (Articulated Train): 22491 lbs. (10.2t)
Car Body RTR Weight: 41895 lbs. (19t)
Vehicle RTR Weight: 64386 lbs. (29.2t)
Design Speed: 155-186 mph.(250-300 kmh)

Y - 225

Table 5

TRUCK UNSPRUNG MASS

	Mass Lb-Sec^2/In (Kg-Sec^2/Cm)	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	8.6 * (1.53)*	35.4 (900)	1/40*-.3*	102.4 (2600)	56.5 (1435)
Total Truck Unsprung	18.2 (3.26)				

TRUCK SPRUNG MASS

	Mass Lb-Sec^2/In (Kg-Sec^2/Cm) Per Truck	Radii of Gyration In. (mm)			TORR to Truck c.g. In (mm)
		Roll	Pitch	Yaw	
Truck Sprung	39.9 (7.14)	34.2* (869)*	34.9* (886)*	48.7* (1237)*	20.3 (515)
Bolster	NA	NA	NA	NA	NA
Truck and Bolster Sprung	NA	NA	NA	NA	NA
Traction Motor	16.7 (2.99) I				
E.M. Brake	3.4* (.61)* I				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec/Cm) Per Truck	Spring Spacings In. (mm)			Damper Spacings In (mm)		
				Vertical From TORR	Lateral	Long.	Vertical From TORR	Lateral	Long.
PRIMARY	Vertical	32000* (5713.6)*	85*-619* (15*-111)*	NA	76.8 (1950)	102.4 (2600)	NA	76.8 (1950)	129.9 (3300)
PRIMARY	Lateral	$2.5x10^4$*-1.6 $x10^7$ ($4.5x10^3$-2.9 $x10^6$)*	40*-25000* (7.1*-4500)*	15.8 (401)	NA	102.4 (2600)	15.8 (401)	NA	102.4 (2600)
PRIMARY	Long.	$2.5x10^4$-1.6 $x10^7$* ($4.5x10^3$-2.9 $x10^5$)*	40*-25000* (7.1*-4500)*	15.8 (401)	76.8 (1950)	NA	17.7 (450)	76.8 (1950)	NA
SECONDARY	Vertical	5000* (892.7)*	310* (55)*	NA	76.8 (1950)	0.	NA	76.8 (1950)	0.
SECONDARY	Lateral	2000* (357)*	93*-279* (17*-50)*	27.0 (686)	NA	27.6 (700)	27.0 (686)	NA	0.
SECONDARY	Long.	38500-10.7 $x10^6$* (6900*-1.9 $x10^6$)*	82*-34000* (15*-6080)*	27.0 (686)	76.8 (1950)	NA	27.0 (686)	76.8 (1950)	NA

		Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
SECONDARY	Roll	NA	NA	NA
SECONDARY	Yaw	NA	$9.3x10^5$-$4.7x10^6$ (1.1-$5.4x10^6$)*	.6 x 10^5* to 3 x 10^5 (.7 x 10^5* to 3.5 x 10^5)*

Truck Type: French Y-226
Car Body: See Table 17
Truck Weight (2 Trucks): 36600 lbs. (16.6t)
Car Body RTR Weight: 99225 lbs. (45t)
Vehicle RTR Weight: 135825 lbs. (61.6t)
Design Speed: 155-186 mph (250 - 300 kmh)

Y - 226

Table 6

TRUCK UNSPRUNG MASS

	Mass Lb-Sec²/In (Kg-Sec²/Cm)	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	8.6* (1.53)*	35.8 (910)	1/40*-.3*	114.1 (2900)	56.5 (1435)
Total Truck Unsprung	Vert. 22 (39) Lat. 45 (8.1)				

TRUCK SPRUNG MASS

	Mass Lb-Sec²/In (Kg-Sec²/Cm) Per Truck	Radii of Gyration In. (mm)			TORR to Truck c.g. In (mm)
		Roll	Pitch	Yaw	
Truck Sprung	Vert.25.4(4.5) Lat.(2.3)(.40)	36.4* (1924)*	33.2* (843)*	50.0* (1270)*	16.9 (430)
Bolster	NA	NA	NA	NA	NA
Truck and Bolster Sprung	NA	NA	NA	NA	NA
Traction Motor	Suspended From Body NI				
E.M. Brake	3.14 (.56) I				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec/Cm) Per Truck	Spring Spacings In (mm)			Damper Spacings In (mm)		
				Vertical From TORR	Lateral	Long.	Vertical From TORR	Lateral	Long.
PRIMARY	Vertical	25000 * (4463.7)*	84*-475* (15*-85)*	NA	90.6 (2300)	114.2 (2900)	NA	96.5 (2450)	114.2 (2900)
	Lateral	1453-9.1x10⁵* (259-1.6x10⁵)*	3*-1450* (1*-259)*	18 (457)	NA	113.6 (3520)	18 (457)	NA	113.6 (3520)
	Long.	1453-9.1x10⁵* (259-1.6x10⁵)*	3*-1450* (1*-259)*	18 (457)	90.6 (2300)	NA	18 (457)	90.6 (2300)	NA
SECONDARY	Vertical	6000* (1017)*	412* (74)*	NA	78.0 (1980)	0.	NA	78.0 (1980)	27.6 (700)
	Lateral	2480* (443)*	53*-159* (9*-28)*	30.7 (780)	NA	0.	30.7 (780)	NA	0.
	Long.	45600-12.7 x10⁶* (8140- 2.3x10⁶)*	97*-40400* (17*-7200)*	30.7 (780)	78.0 (1980)	NA	30.7 (780)	98.4 (2500)	NA

		Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
SECONDARY	Roll	NA	NA	NA
	Yaw	NA	NA	1.5×10^5* to 7.5×10^5* (1.7×10^5* to 8.6×10^5*)

Truck Type:	Italian Fiat Eurofa
Car Body:	See Table 17
Truck Weight (2 Trucks):	31000 lbs. (14t)
Car Body RTR Weight:	66150 lbs. (30t)
Vehicle RTR Weight:	97150 lbs. (44t)
Design Speed:	125 to 155 mph (200 to 250 kmh)

Fiat Eurofa

Table 7

TRUCK UNSPRUNG MASS

	Mass Lb-Sec²/In (Kg-Sec²/Cm)	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	8.6 (1.53)	36.2 (920)	1/40*-.3*	102.4 (2600)	56.5 (1435)
Total Truck Unsprung	17.2 (3.06)				

TRUCK SPRUNG MASS

	Mass Lb-Sec²/In (Kg-Sec²/Cm) Per Truck	Radii of Gyration In. (mm) Roll	Pitch	Yaw	TORR to Truck c.g. In (mm)
Truck Sprung	19.7* (3.52)*	36.9* (937)*	29.3* (744)*	47.3* (3048)*	15.7 (400)
Bolster	NA	NA	NA	NA	NA
Truck and Bolster Sprung	NA	NA	NA	NA	NA
Traction Motor	Unpowered				
E.M. Brake	3.40 (.61) NI				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec/Cm) Per Truck	Spring Spacings In (mm) Vertical From TORR	Spring Spacings Lateral	Spring Spacings Long.	Damper Spacings In (mm) Vertical From TORR	Damper Spacings Lateral	Damper Spacings Long.
PRIMARY	Vertical	14000 (2500)	53*-266* (9*-47*)	NA	79.1 (2010)	102.4 (2600)	NA	79.1 (2010)	122.0 (3100)
PRIMARY	Lateral	26000 (4650)	29*-716* (5*-128*)	17.7 (450)	NA	70.1 (1780)	18.1 (460)	NA	70.1 (1780)
PRIMARY	Long.	170260 (30400)	73*-1831* (13*-327*)	17.7 (450)	78.7 (2000)	NA	18.1 (460)	78.7 (2000)	NA
SECONDARY	Vertical	4667 to 4870 (833 to 870)	343* (61)*	NA	79.1 (2010)	0.	NA	105.1 (2670)	0.
SECONDARY	Lateral	1867 to 1931 (333 to 345)	81* to 247* (17* to 53)*	26.5 (673)	NA	0.	26.5 (673)	NA	0
SECONDARY	Long.	30400-8.4x10⁶* (5430*-1.5x10⁶	65*-26800* (12*-4800)*	26.5 (673)	79.1 (2010)	NA	26.5 (673)	105.1 (2670)	NA

SECONDARY		Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
	Roll	$2.5x10^6$* ($2.9x10^6$)*	NA	NA
	Yaw	NA	$1.6-8.1x10^6$* ($1.8-9.3x10^6$)*	1 x 10^5* to 5 x 10^5* (1.2 x 10^5 to 6 x 10^5)*

Truck Type: Italian Z1040
Car Body: See Table 17
Truck Weight (2 Trucks): 66150 lbs. (30.0t)
Car Body RTR Weight: 72765 lbs. (33.0t)
Vehicle RTR Weight: 138915 lbs. (63.0t)
Design Speed: 149 mph (240 kmh)

Z 1040

Table 8

TRUCK UNSPRUNG MASS

	Mass Lb-Sec²/In (Kg-Sec²/Cm)	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	12.8* (2.3*)	40.9 (1040)	1/40*-.3*	118.1 (3000)	56.5 (1435)
Total Truck Unsprung	25.7* (4.59)*				

TRUCK SPRUNG MASS

	Mass Lb-Sec²/In (Kg-Sec²/Cm) Per Truck	Radii of Gyration In. (mm)			TORR to Truck c.g. In (mm)
		Roll	Pitch	Yaw	
Truck Sprung	28.5* (5.10)*	34.9* (886)*	40.9* (1039)*	53.5* (1359)*	31.5 (800)
Bolster	4.0* (1.71)*	26.9* (683)*	13.3* (338)*	30.0* (762)*	11.0 (280)
Truck and Bolster Sprung	32.5* (5.81)*	34.7* (881)*	39.2* (995)*	51.2* (1301)*	29. (737)
Traction Motor	27.4 4.89 NI				
E.M. Brake	NA				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec/Cm) Per Truck	Spring Spacings In (mm)			Damper Spacings In (mm)		
				Vertical From TORR	Lateral	Long.	Vertical From TORR	Lateral	Long.
PRIMARY	Vertical	11668 (2083)	58*-327* (10*-58*)	NA	78.7 (2000)	118.1 (3000)	NA	78.7 (2000)	118.1 (3000)
	Lateral	$20.5 \times 10^4 - 1.28 \times 10^7$* ($3.7 \times 10^4 - 2.3 \times 10^6$*)	103*-20400* (18*-3600*)	20.5 (520)	NA	118.1 (3000)	20.5 (520)	NA	118.1 (3000)
	Long.	$20.5 \times 10^4 - 1.28 \times 10^7$ ($3.7 \times 10^4 - 2.3 \times 10^6$*)	103-20400* (18*- 3600*)	20.5 (520)	78.7 (2000)	NA	20.5 (521)	78.7 (2000)	NA
SECONDARY	Vertical	5186 (926)	413* (74*)	NA	81.1 (2060)	16.9 (430)	NA	93.7 (2380)	0.
	Lateral	1750* (312)*	81* to 242* (17* to 52*)	21.7 (550)	NA	39.4 (1000)	18.9 (481)	NA	18.9 (480)
	Long.	33500*-9.3 $\times 10^6$* (5980-1.7$\times 10^6$*)	71*-29600* (13*-5280*)	21.7 (550)	81.1 (2060)	NA	21.7 (550)	81.1 (2060)	NA

SECONDARY		Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
	Roll	NA	NA	NA
	Yaw	NA	NA	1.5×10^5* to 7.5×10^5* (1.7×10^5* to 8.6×10^5*)

Truck Type: German MAN ET-403
Car Body: See Table 17
Truck Weight (2 Trucks): 51160 lbs. (23.2t)
Car Body RTR Weight: 70560 lbs.*(32t*)
Vehicle RTR Weight: 121720 lbs. (55.2t)
Design Speed: 125 mph (200 kmh)

ET 403

Table 9

TRUCK UNSPRUNG MASS

	Mass Lb-Sec^2/In (Kg-Sec^2/Cm)	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	11.4 (2.04).	41.3 (1050)	1/40*-.3*	102.4 (2600)	56.5 (1435)
Total Truck Unsprung	26.3 (4.69)				

TRUCK SPRUNG MASS

	Mass Lb-Sec^2/In (Kg-Sec^2/Cm) Per Truck	Radii of Gyration In. (mm)			TORR to Truck c.g. In (mm)
		Roll	Pitch	Yaw	
Truck Sprung	39.9 (7.14)	34.7* (881)*	44.0* (1118)*	52.3* (1318)*	21.3 (540)
Bolster	NA	NA	NA	NA	NA
Truck and Bolster Sprung	NA	NA	NA	NA	NA
Traction Motor	Powered I				
E.M. Brake	34* (.61*) I				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec/Cm) Per Truck	Spring Spacings In (mm)			Damper Spacings In (mm)		
				Vertical From TORR	Lateral	Long.	Vertical From TORR	Lateral	Long.
PRIMARY	Vertical	42560 (7600)	103*-1119* (18*-200*)	NA	78.7 (2000)	102.4 (2600)	NA	78.7 (2000)	88.6 (2250)
	Lateral	28009- 302000 (5000 - 54000)	42*-3470* (7*-62*)	21.3 (540)	NA	102.4 (2600)	21.3 (540)	NA	102.4 (2600)
	Long.	26900- 240000 (4800 -53000)	41*-3090* (7*-553*)	21.3 (540)	78.7 (2000)	NA	21.3 (540)	78.7 (2000)	NA
SECONDARY	Vertical	4400* (786)*	250* (45*)	NA	78.7 (2000)	0.	NA	100.0 (2540)	29.5 (750)
	Lateral	3600* (643)*	115* to 344* (25* to 74*)	34.1 (865)	NA	0.	34.1 (865)	NA	0.
	Long.	32400*-9. x10^6* (5780-1.6 x10^6*)	69*-28700* (12*-5120*)	34.1 (865)	78.7 (2000)	NA	34.1 (965)	100 (2540)	NA

	Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
Roll	NA	NA	NA
Yaw	NA	NA	1.2 x 10^5* to 6 x 10^5* (1.4 x 10^5* to 7 x 10^5*)

Truck Type: German Minden Deutz
Car Body: See Table 16
Truck Weight (2 Trucks): 30429 lbs. (13.8t)
Car Body RTR Weight: 62181 lbs. (28.2t)
Vehicle RTR Weight: 92610 lbs. (42.0t)
Design Speed: 125 mph (200 kmh)

Minden Deutz

Table 10

TRUCK UNSPRUNG MASS

	Mass Lb-Sec²/In (Kg-Sec²/Cm)	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	9.7* (1.73)*	37.6 (950)	1/40*-.3*	99. (2500)	56.5 (1435)
Total Truck Unsprung	19.4* (3.46)*				

TRUCK SPRUNG MASS

	Mass Lb-Sec²/In (Kg-Sec²/Cm) Per Truck	Radii of Gyration In. (mm)			TORR to Truck c.g. In (mm)
		Roll	Pitch	Yaw	
Truck Sprung	13* (2.32)*	35.1* (892)*	38.2* (970)*	51.9* (1318)*	30.9 (785)
Bolster	3.4 * (.61)*	24.9* (632)*	9.4* (239)*	26.9* (683)*	12.2 (310)
Truck and Bolster Sprung	16.4* (2.93)*	33.9* (861)*	35.1* (891)*	47.8* (1215)*	27.0 (686)
Traction Motor	Unpowered				
E.M. Brake	3.4* (.61)* NI				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec/Cm) Per Truck	Spring Spacings In (mm)			Damper Spacings In (mm)		
				Vertical From TORR	Lateral	Long.	Vertical From TORR	Lateral	Long.
PRIMARY	Vertical	14000* (2500)*	52*-270* (9*-48*)	NA	79.2 (2000)	98.4 (2500)	NA	93.9 (2370)	98.4 (2500)
	Lateral	1.04 $x10^4$*-6.5 $x10^6$ (1.9 $x10^3$*-1.2 $x10^6$*)	17*-10300* (3*-1840*)	18.7 (475)	NA	98.4 (2500)	18.7 (475)	NA	98.4 (2500)
	Long.	1.04 $x10^4$*-6.5 $x10^6$* (1.9 $x10^3$*-1.2 $x10^6$)	17*-10300* (3*-1840*)	18.7 (475)	79.2 (2000)	NA	18.7 (475)	79.2 (2000)	NA
SECONDARY	Vertical	3800* (678)*	270* (48*)	NA	79.2 (2000)	15. (380)	NA	94.5 (2400)	0.
	Lateral	1500* (268)*	70* to 210* (12.5* to 37.5*)	25.6 (650)	NA	0.	25.6 (650)	NA	0.
	Long.	28600*-7.9 $x10^6$* (5100-1.4 $x10^6$*)	61*-25200* (11*-4500*)	30.2 (767)	97.1 (2467)	NA	30.2 (767)	97.1 (2467)	NA

		Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
SECONDARY	Roll	2.5 $x10^6$* (2.9 $x10^6$*)	NA	NA
	Yaw	NA	NA	.9 x 10^5* to 4.5 x 10^5* (1. x 10^5* to 5.2 x 10^5*)

Truck Type: Japanese DT200
Car Body: See Table 17
Truck Weight (2 Trucks): 44100 lbs. (20t)
Car Body RTR Weight: 74970 lbs. (34t)
Vehicle RTR Weight: 119070 lbs. (54t)
Design Speed: 125 mph (200 kmh)

DT 200

Table 11

TRUCK UNSPRUNG MASS

	Mass Lb-Sec^2/In (Kg-Sec^2/Cm)	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	9.0* (1.61*)	35.8 (910)	1/40	98.4 (2500)	56.5 (1435)
Total Truck Unsprung	22.8 (4.07)				

TRUCK SPRUNG MASS

	Mass Lb-Sec^2/In (Kg-Sec^2/Cm) Per Truck	Radii of Gyration In. (mm)			TORR to Truck c.g. In (mm)
		Roll	Pitch	Yaw	
Truck Sprung	29* (5.18)*	39.1* (993)*	34.2* (869)*	51.8* (1316)*	21.7 (550)
Bolster	5.2* (.93*)	35.4* (899*)	5.9* (150)*	35.1* (892)*	39.7 (1008)
Truck and Bolster Sprung	34.2 (6.11)	39.1* (993)	32.2* (818)*	49.6* (1260)*	24.4 (.96)
Traction Motor **	Powered				
E.M. Brake	NA				

** From available sources unclear if mass included in truck sprung

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec/Cm) Per Truck	Spring Spacings In. (mm)			Damper Spacings In (mm)		
				Vertical From TORR	Lateral	Long.	Vertical From TORR	Lateral	Long.
PRIMARY	Vertical	28000 (5000)	448 (80)	NA	82.7 (2100)	98.4 (2500)	NA	100.4 (2550)	98.4 (2500)
PRIMARY	Lateral	168000-224000 (30000-40000)	96*-2768* (17*-494*)	17.7 (450)	NA	98.4 (2500)	17.7 (450)	NA	98.4 (2500)
PRIMARY	Long.	336000-448000 (60000-80000)	136*-3914* (24*-699*)	17.7 (459)	98.4 (2500)	NA	17.7 (450)	98.4 (2500)	NA
SECONDARY	Vertical	4480 (800)	227 (49.5)	NA	98.4 (2500)	0.	NA	98.4 (2500)	0.
SECONDARY	Lateral	4032 (720)	560 (100)	41.3 (1050)	NA	0.	41.3 (1050)	NA	23.6 (600)
SECONDARY	Long.	34500-9.6x10^6* (6160*-1.7 x10^6*)	73*-30500* (13*-5400*)	22.0 (560)	114.2 (2900)	NA	22.0 (560)	114.2 (2900)	NA

		Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
SECONDARY	Roll	NA	NA	NA
SECONDARY	Yaw	NA	NA	1.2 x 10^5* to 6 x 10^5* (1.4 x 10^5* to 6.9 x 10^5*)

Truck Type:	Canadian LRC Dofasco
Car Body:	See Table 17
Truck Weight (2 Trucks):	29200 lbs. (13.2 t)
Car Body RTR Weight:	60400 lbs. (27.4 t)
Vehicle RTR Weight:	89600 lbs. (40.6 t)
Design Speed:	125 mph (200 kmh)

LRC

Table 12

TRUCK UNSPRUNG MASS

	Mass $Lb\text{-}Sec^2/In$ $(Kg\text{-}Sec^2/Cm)$	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	6.6 (1.18)	30. (762)	1/40 - 1/5	97 (2464)	56.5 (1435)
Total Truck Unsprung	13.2 (2.36)				

TRUCK SPRUNG MASS

	Mass $Lb\text{-}Sec^2/In$ $(Kg\text{-}Sec^2/Cm)$ Per Truck	Radii of Gyration In. (mm) Roll	Pitch	Yaw	TORR to Truck c.g. In (mm)
Truck Sprung	19.0 (3.39)	21.6 (549)	31 (787)	36.25 (921)	17.9 (455)
Bolster	5.74 (1.02)	35 (889)	14.5 (368)	37.2 (945)	28.9 (734)
Truck and Bolster Sprung	24.74 (4.41)	25.8 (655)	28.4 (721)	36.5 (927)	20.5 (521)
Traction Motor	Unpowered				
E.M. Brake	NA				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec/Cm) Per Truck	Spring Spacings In (mm) Vertical From TORR	Spring Lateral	Spring Long.	Damper Spacings In (mm) Vertical From TORR	Damper Lateral	Damper Long.
PRIMARY	Vertical	17000 (3035)	200 (36)	NA	44.0 1118	97 (2464)	NA	33 (838)	97 (2464)
PRIMARY	Lateral	34000 (6071)	73-146 (13-26)	16 (406)	NA	97 (2464)	16 (406)	NA	97 (2464)
PRIMARY	Long.	230000 (41066)	191-382 (34-68)	16 (406)	44.0 1118	NA	16 (406)	44 (1118)	NA
SECONDARY	Vertical	2068 (369)	250 (45)	NA	88 (2235)	0.	NA	88 (2235)	39 (991)
SECONDARY	Lateral	1500 (268)	200 (36)	26-31 (660-787)	NA	0-355 (0-902)	28 (711)	NA	50 (1270)
SECONDARY	Long.	30000 (5356)	1125 (201)	26-31 (660-787)	0-64 (0-1626)	NA	12.4 (314)	92 (2337)	NA

SECONDARY	Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In-Lb (Kg-Cm)
Roll	Tilt Control	NA	NA
Yaw	NA	NA	138000 (159000)

Truck Type: English BT10
Car Body: See Table 17
Truck Weight (2 Trucks): 25578 lbs. (11.6t)
Car Body RTR Weight: 47187 lbs. (21.4t)
Vehicle RTR Weight: 72765 lbs. (33t)
Design Speed: 125 mph (200kmh)

BT 10

Table 13

TRUCK UNSPRUNG MASS

	Mass $Lb\text{-}Sec^2/In$ ($Kg\text{-}Sec^2/Cm$)	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	6.8* (1.22)*	36.0 (914)	1/40*-.3*	102.4 (2600)	56.5 (1435)
Total Truck Unsprung	13.7* (2.45)*				

TRUCK SPRUNG MASS

	Mass $Lb\text{-}Sec^2/In$ ($Kg\text{-}Sec^2/Cm$) Per Truck	Radii of Gyration In. (mm)			TORR to Truck c.g. In (mm)
		Roll	Pitch	Yaw	
Truck Sprung	13.7* (2.45)*	35.9* (912)*	37.6* (955)*	52.0* (1321)*	30.7 (780)
Bolster	5.7* (1.02)*	30.7* (780)*	11.1* (282)*	32.7* (831)*	13. (330)
Truck and Bolster Sprung	19.4* (3.47)*	35.4* (899)*	33.2* (843)*	37.1* (1197)*	25.5
Traction Motor	Unpowered				
E.M. Brake	NA				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec /Cm) Per Truck	Spring Spacings In (mm)			Damper Spacings In (mm)		
				Vertical From TORR	Lateral	Long.	Vertical From TORR	Lateral	Long.
PRIMARY	Vertical	23000* (4107)*	56*-467* (10*-83*)	NA	80 (2032)	102.4 (2600)	NA	80 (2032)	102.4 (2600)
	Lateral	$12250\text{-}7.7X10^6$* ($2187\text{-}1.4x10^6$*)	19*-12200* (3*-2180*)	18 (457)	NA	102.4 (2600)	18 (458)	NA	102.4 (2600)
	Long.	$12250\text{-}7.7x10^6$* ($2187\text{-}1.4x10^6$*)	19*-12200* (3*-2180*)	18 (457)	80 (2032)	NA	18 (458)	80 (2032)	NA
SECONDARY	Vertical	3000* (536)*	175* (31*)	NA	78.0 (1982)	0.	NA	99.6 (2530)	22.4 (570)
	Lateral	900* (161)*	47*-141* (8*-25*)	24.8 (630)	NA	0.	24.8 (630)	NA	27 (685)
	Long.	$21700\text{-}6.0x10^6$* ($3870\text{-}1.1x10^6$*)	46*-19100* (8*-3400*)	18 (457)	78 (1982)	NA	18 (457)	78 (1982)	NA

		Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
SECONDARY	Roll	NA	NA	NA
	Yaw	NA	NA	$.7 \times 10^5$* to 3.5×10^5* ($.8 \times 10^5$* to 4×10^5*)

Truck Type: Russian ER 200
Car Body: See Table 17
Truck Weight (2 Trucks): 57330 lbs. (26t)
Car Body RTR Weight: 70119 lbs. (31.8t)
Vehicle RTR Weight: 127449 lbs. (57.8t)
Design Speed: 125 mph (200 kmh)

ER 200

Table 14

TRUCK UNSPRUNG MASS

	Mass Lb-Sec²/In (Kg-Sec²/Cm)	Diameter In (mm)	Concity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	9.7* (1.73)*	37.4 (950)	1/40*-.3*	98.4 (2500)	60.0 (1524)
Total Truck Unsprung	22.8* (4.08)*				

TRUCK SPRUNG MASS

	Mass Lb-Sec²/In (Kg-Sec²/Cm) Per Truck	Radii of Gyration In. (mm)			TORR to Truck c.g. In (mm)
		Roll	Pitch	Yaw	
Truck Sprung	42.6* (7.43)*	38.4* (975)*	36.9* (937)*	52.9* (1344)*	19.7 (500)
Bolster	5.2* (.93)*	28.5* (724)*	4.9* (124)*	28.7* (729)*	36.3 (922)
Truck and Bolster Sprung	47.8* (8.53)*	37.8* (960)*	35.8* *894)*	50.8* (1290)*	21.5 (546)
Traction Motor	Powered I				
E.M. Brake	3.6* (.64)* NI				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec/Cm) Per Truck	Spring Spacings In (mm)			Damper Spacings In (mm)		
				Vertical From TORR	Lateral	Long.	Vertical From TORR	Lateral	Long.
PRIMARY	Vertical	31000 (5535)	109*-944* (19*-169*)	NA	82.7 (2100)	98.4 (2500)	NA	95.3 (2420)	98.4 (2500)
PRIMARY	Lateral	$3.2x10^{4}-2x10^{7}$* ($5.7x10^{3}-3.6x10^{6}$*)	51*-32000* (9*-5700*)	18.7 (475)	NA	98.4 (2500)	18.7 (475)	NA	98.4 (2500)
PRIMARY	Long.	$3.2x10^{4}-2x10^{7}$* ($5.7x10^{3}-3.6x10^{6}$*)	51*-32000* (9*-5700*)	18.7 (475)	82.7 (2100)	NA	18.7 (475)	82.7 (2100)	NA
SECONDARY	Vertical	5850 (1045)	432* (77*)	NA	82.7 (2100)	0.	NA	117.3 (2980)	0.
SECONDARY	Lateral	3200* (571*)	145*-436* (26*-78*)	37.4* (950)*	NA	0.	36.2* (920)*	NA	19.7 (500)
SECONDARY	Long.	$58600-16.3x10^{6}$* ($10500-2.9x10^{6}$*)	124*-51800* (22.1-9200*)	24.6 (625)	108.1 (2746)	NA	24.6 (625)	108.1 (2746)	NA

SECONDARY		Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
	Roll	NA	NA	NA
	Yaw	NA	NA	$1.8 x 10^{5}$* to $9. x 10^{5}$* ($2.1 x 10^{5}$* to $10.4 x 10^{5}$*)

Truck Type: P-III
Car Body: See Table 17
Truck Weight (2 Trucks): 27420 lbs. (12.4t)
Car Body RTR Weight: 76950 (34.9t)
Vehicle RTR Weight: 104370 lbs. (47.3t)
Design Speed: 120 mph (193 kmh)

P - III

Table 15

TRUCK UNSPRUNG MASS

	Mass Lb-Sec^2/In (Kg-Sec^2/Cm)	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	8.9 (1.6)	36. (914)	1/20	102. (2591)	56.5 (1435)
Total Truck Unsprung	17.8 (3.2)				

TRUCK SPRUNG MASS

	Mass Lb-Sec^2/In (Kg-Sec^2/Cm) Per Truck	Radii of Gyration In. (mm)			TORR to Truck c.g. In (mm)
		Roll	Pitch	Yaw	
Truck Sprung	9.8 (1.7)	31.5 (800)	19.1 (485)	38.1 (968)	18.6 (472)
Bolster	7.9 (1.4)	37.2 (945)	8.7 (221)	37.4 (950)	26.3 (668)
Truck and Bolster Sprung	17.7 (3.2)	34.4 (873)	15.8 (402)	37.8 (960)	22.2 (564)
Traction Motor	Unpowered				
E.M. Brake	NA				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec/Cm) Per Truck	Spring Spacings In (mm)			Damper Spacings In (mm)		
				Vertical From TORR	Lateral	Long.	Vertical From TORR	Lateral	Long.
PRIMARY	Vertical	645000 (115164)	357* to 1000* (77* to 216*)	NA	46. (1168)	102. (2591)	NA	46 (1168)	102 (2591)
PRIMARY	Lateral	4100000. (732051)	340*-8500* (61*-1520*)	18 (457)	NA	102. (2591)	18 (457)	NA	102 (2591)
PRIMARY	Long.	1180000. (210688)	183*-4570* (33*-816*)	18. (457)	46. (1168)	NA	18 (457)	46 (1168)	NA
SECONDARY	Vertical	3700 (661)	240 (43)	NA	90. (2286)	0.	NA	87. (2210)	0.
SECONDARY	Lateral	4000 (714)	200 (36)	40. (1016)	NA	0.	29. (737)	NA	0.
SECONDARY	Long.	25000 (4464)	78 (14)	20. (508)	108. (2743)	NA	20. (508)	108. (2743)	NA

		Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In - Lb (Kg - Cm)
SECONDARY	Roll	NA	NA	NA
SECONDARY	Yaw	NA	NA	.9 x 10^5 (1 x 10^5)

Truck Type: GSI Metroliner
Car Body: See Table 17
Truck Weight (2 Trucks): 47246 lbs. (21.4t)
Car Body RTR Weight: 105205 lbs (47.7t)
Vehicle RTR Weight: 152451 lbs (69.1t)
Design Speed: 160 mph (258 kmh)

Metroliner

Table 16

TRUCK UNSPRUNG MASS

	Mass $Lb\text{-}Sec^2/In$ $(Kg\text{-}Sec^2/Cm)$	Diameter In (mm)	Conicity N.D.	Wheelbase In (mm)	Track Gauge In (mm)
Wheelset	12.5 (2.23)	36. (914)	1/20	102 (2591)	56.5 (1435)
Total Truck Unsprung	29.1 (5.20)				

TRUCK SPRUNG MASS

	Mass $Lb\text{-}Sec^2/In$ $(Kg\text{-}Sec^2/Cm)$ Per Truck	Radii of Gyration In. (mm)			TORR to Truck c.g. In (mm)
		Roll	Pitch	Yaw	
Truck Sprung	25.2 (4.50)	24.6 (625)	31.2 (792)	37.5 (953)	20.3 (516)
Bolster	6.9 (1.23)	37.2 (945)	8.7 (221)	37.4 (950)	27.6 (701)
Truck and Bolster Sprung	32.1 (5.73)	28.6 (726)	28.1 (714)	37.5 (953)	21.9 (556)
Traction Motor	10.8 (1.93) I				
E.M. Brake	NA				

TRUCK SUSPENSION

		Stiffness Lb/In (Kg/Cm) Per Truck	Damping Lb-Sec/In (Kg-Sec /Cm) Per Truck	Spring Spacings In (mm)			Damper Spacings In (mm)		
				Vertical From TORR	Lateral	Long.	Vertical From TORR	Lateral	Long.
PRIMARY	Vertical	109000 (19462)	260 (46.4)	NA	79 (2007)	57.5 (1461)	NA	79 (2007)	102 (2591)
PRIMARY	Lateral	55800 (9963)	260 (46.4)	18 (457)	NA	57.5 (1461)	18 (457)	NA	102 (2591)
PRIMARY	Long.	55800 (9963)	260 (46.4)	18 (457)	79 (2007)	NA	18 (457)	79 (2007)	NA
SECONDARY	Vertical	7740 (1382)	115 (20.5)	NA	92 (2337)	0	NA	99 (2515)	0
SECONDARY	Lateral	3386 (605)	173 (30.9)	39 (991)	NA	0	37 (940)	NA	0
SECONDARY	Long.	96660 (17259)	78 (13.9)	21 (533)	108 (2743)	NA	21 (533)	108 (2743)	NA

		Stiffness In-Lb/Rad (Kg-Cm/Rad)	Damping Lb-Sec-In (Kg-Sec-Cm)	Frictional Restraint In-Lb (kg-Cm)
SECONDARY	Roll	NA	NA	NA
SECONDARY	Yaw	NA	NA	1.7×10^5-8.5×10^5 (1.96×10^5-9.8×10^5)

4.3 Car Data

Car body data for each high speed truck in Section 3.2 are provided in this section. The data are organized in a common engineering format and include such parameters as body mass, radii of gyration, geometry, and the first flexible car body frequency. These data are presented in one line of the table to enable comparisons to be made by looking at the the table.

The car center of gravity unless definitely specified was assumed to be at the geometric center in both the lateral and longitudinal directions and one-third the height from the floor to roof in the vertical direction.

The radii of gyration calculations were based on a car body weight distribution of half in the car floor, one-sixth in the roof, and one-sixth at each side.

The following two pages show the tabulated car body data.

Table 17

CAR BODY PARAMETERS

Car Type	Truck Type	Mass Lb-Sec²/In (Kg-Sec²/Cm)			Radii of Gyration In(mm)			Dimensions In. (mm)						Car Body First Vertical Flexible Freq.Hz.
								Longitudinal		Lateral	Vertical			
		RTR	Seated	Crush	Roll	Pitch	Yaw	Car Length	Truck Spacing	Car Width	TORR To Floor	TORR To Cg.	Car Height	
French A^9U	Y-32	181.6 (32.4)	210.7* (37.6)*	239.8* (42.8*)	63* (1600)*	306* (7772)*	306* (7772)*	1039.4 (26400)	748.0 (19000)	111.2 (2825)	42 (1067)	81.5* (2069)*	118.4 (2990)	8.5
Eurofina A^4B^6	FIAT Eurofa	171.2 (30.6)	200* (35.7)*	228.8* (40.8*)	63* (1600)*	306* (7772)*	306* (7772)*	1039.4 (26400)	748.0 (19000)	111.6 (2835)	42.5 (1080)	81.5* (2069)*	116.9 (2970)	8.5
French A^8tu	Y-28	216.8 (38.7)	239.8* (42.8)*	262.8* (46.9*)	63* (1600)*	293* (7442)*	335* (8509)*	1003.9 (25500)	712.6 (18100)	111.4 (2830)	41.7 (1060)	80.9* (2056)*	117.7 (2990)	10*
Japan NTL	DT200	194.0 (34.6)	222.3* (39.7)*	250.6* (44.8*)	68* (1727)*	284* (7214)*	284* (7214)*	984.3 (25000)	689.0 (17500)	133.1 (3380)	39.4 (1000)	78.8* (2001)*	118.1 (3000)	6.1
French RTG (Trailer Car)	Y224	169.5 (30.3)	1981.1* (35.4)*	226.7* (40.5*)	63* (1600)*	296* (7520)*	296 (7520)	1004.3 (25510)	651.2 (16540)	115.4 (2930)	41.3 (1050)	55.1 (1400)	102.4 (2600)	10
German ET 403	MAN	183 * (32.6)*	205.5* (36.7)*	228* (40.8*)	61* (1549)*	312* (7925)*	312* (7925)	1069.3 (27160)	748.0 (19000)	110.0 (2795)	51.1 (1300)	89.1* (2263)*	114. (2900)	9
Italian ALE 601	Z 1040	188.3 (33.6)	211.1 (37.7)	216.9* (38.7*)	59.5* (1511)*	314* (7976)*	314* (7976)*	1078.7 (27400)	716.5 (18200)	113.0 (2870)	42.3 (1075)	77.6* (1971)*	105.9 (2690)	10*
French TGV Trailer	Y-225	108 (19.46)	134.7* (24.05)*	161.4* (28.6*)	59. * (1499)*	203.* (5156)*	203.* (5156)*	720.5 (18300)	720.5 (18300)	110.7 (2814)	39.4 (1000)	70.9* (1801)*	94.5 (2400)	6*-10*

Table 17, Continued

CAR BODY PARAMETERS

Car Type	Truck Type	Mass $Lb\text{-}Sec^2/In$ ($Kg\text{-}Sec^2/Cm$)			Radii of Gyration In(mm)			Dimensions In. (mm)						Car Body First Vertical Flexible Freq.Hz.
								Longitudinal		Lateral	Vertical			
		RTR	Seated	Crush	Roll	Pitch	Yaw	Car Length	Truck Spacing	Car Width	TORR To Floor	TORR To Cg.	Car Height	
French Z 7001	Y-226	256.8 (45.9)	302.4* (54.0)*	348.* (62.1*)	63* (1600)*	323* (8204)*	323* (8204)*	1102.4 (28000)	685.0 (17400)	112.2 (2850)	42.3 (1075)	81.7* (2075)*	118.1 (3000)	6*-10
Canadian LRC	Dofasco	156.3 (27.9)	196.1* (35.0)	235.9* (42.1*)	55* (1397)*	294* (7468)*	294* (7468)*	1020.0 (25908)	714 (18136)	125 (3175)	42 (1067)	75* (1905)	99 (2515)	9.2
English HST Mark III	BT 10	122.1 (21.8)	155.2* (27.7)*	188.3* (33.6*)	51* (1295)*	268* (6807)*	268* (6807)*	905.5 (23000)	630. (16000)	103.1 (2620)	40.9 (1040)	78* (1981)*	112.1 (2848)	10.
Russian ER 200		181.5 (32.4)	218.1 (38.9)	254.7* (45.4*)	64* (1626)*	298* (7569)*	298* (7569)*	1023.6 (26000)	40.2 (18800)	121.3 (3080)	48.8 (1240)	86.6* (2200)*	113.4 (2880)	8.3
German Mainline Coach	Minden Deutz	160.9 (28.7)	195.2* (34.9)*	229.5* (41.1*)	61* (1549)*	303* (7696)*	303* (7696)*	1039.4 (26400)	748. (19000)	115.2 (2925)	49.4 (1256)	86.1* (2186)*	110 (2794)	8.75 to 10
Amcoach	P-III	199.1 (35.5)	238.3 (42.5)	277.4 (49.5)	62* (1575)*	298* (7569)*	298* (7569)*	1024. (26010)	714. (18136)	126. (3200)	52.8 (1341)	75.3 (1913)	101 (2565)	7.5
Metro-liner	GSI	272.3 (48.6)	307.7 (48.6)	343.1 (61.3)	45 (1143)	299 (7595)	297 (7544)	1020 (25908)	714 (18136)	126 (18136)	50.75 (1289)	62.4 (1585)	161 (2565)	6.8 to 7.5

Metroliner Mass Excludes Transformer - 32.0
(5.7)

5. INFLUENCE OF TRUCK SUSPENSION PARAMETER VARIATIONS ON RAILCAR DYNAMIC RESPONSE

The influence of truck suspension on vehicle dynamic response is characterized by the changes in natural frequencies and associated modal dampings of the vehicle dynamic system associated with changes in the truck suspension parameters. The railcars using the 15 trucks described previously have many features in common which allow a common approach to characterizing their dynamic response, namely:

(1) Individual cars are approximately symmetrical about a vertical-transverse plane through the car body center of gravity. This allows the vertical input to the trucks due to rail irregularities to be partitioned into the average of the two truck motions which drives purely symmetrical vertical vibrations, and the out-of-phase motions which drive purely anti-symmetric (pitch) vertical vibrations.

(2) Individual cars are approximately symmetrical about a vertical-longitudinal plane through the car body center of gravity. This completely uncouples the roll and lateral dynamics from the vertical and pitch dynamics. This and the preceding symmetry completely uncouple the anti-symmetric (yaw) dynamics from the other dynamic responses.

(3) The symmetric vertical responses of all 15 cars have a lowest resonant frequency which is well approximated as a rigid car bouncing on the primary and secondary vertical suspensions in series (the car bounce frequency).

(4) All 15 cars have the two lowest resonant frequencies in response to roll and/or lateral wheelset inputs well approximated by the response of the two degree of freedom system consisting of the rigid car on its lateral and vertical truck suspension, where the primary and secondary springs are in series and the truck sprung mass is neglected (referred to as the lower and upper car roll-lateral resonant frequencies).

For the 15 high speed trains described in this report, the car bounce, lower and upper roll-lateral, and rigid-body car pitch and yaw resonant frequencies are all between 0.5 Hz and 2 Hz. These frequencies are controlled to a large extent by the secondary vertical and lateral spring stiffnesses. A 10% change in secondary spring stiffness will cause between 7% and 10% change in overall vertical stiffness (between 3.5%

change in car bounce resonant frequency). However, a 10% change in primary spring stiffness will cause only between 0% and 2.5% change in overall vertical stiffness. The overall lateral rate is even more closely controlled by the secondary lateral stiffness than is the vertical rate by the secondary vertical stiffness.

The resonant frequencies between 0.5 and 2 Hz should be as low as possible so that good riding qualities will ensue, by virtue of the isolation of the car body from track irregularities at frequencies above these resonances. Sufficient damping must be provided in these modes to control the resonant car body accelerations, yet the damping should be moderate since it provides a path for transmission of vibrations at higher frequencies.

All 15 truck suspensions have some vertical damping in both the primary and secondary suspensions. For trucks where data is available, the modal damping at the car bounce frequency is between 13% and 20% of critical damping. The car bounce modal damping is largely controlled by the damping in the secondary vertical suspension, and this damping is higher than it would have to be if it were connected from car body to unsprung mass.

A formula for estimating modal damping of the car body bounce resonant mode is

$$\%\ \text{of Critical Damping} = \frac{C_p \left(\frac{ks}{kp + ks}\right)^2 + C_s \left(\frac{kp}{kp + ks}\right)^2}{2m \quad W_m}$$

Where C_p = Vertical damping in primary suspension, $\frac{\text{lb sec}}{\text{in}}$

C_s = Vertical damping in secondary suspension, $\frac{\text{lb sec}}{\text{in}}$

k_p = Vertical stiffness in primary suspension, $\frac{\text{lb}}{\text{in}}$

k_s = Vertical stiffness in secondary suspension, $\frac{\text{lb}}{\text{in}}$

m = Mass of 1/2 the Car Body, $\frac{lb\ sec^2}{in}$

W_m = Resonant Car Bounce Frequency, rad./sec

The range of fractions of critical damping found in the 15 trucks tabulated controls resonant acceleration and also should serve to maintain the car body within its clearance envelope as defined by the bumpers, for all but relatively large track irregularity inputs which occur relatively infrequently. In other words, the low frequency modal damping serves to prevent frequent vertical bumper contact. A lower bound on the car bounce resonant frequency is set by the criterion for infrequent bumper contact as well as acceptably low car floor vertical acceleration levels.

The damping in the lateral truck suspensions is not well specified in the literature. It is also hard to estimate since the 15 railcars studied have ratios of lateral secondary to net vertical spring rate which ranges from 0.27 to 1.1 Also, some of the trucks studied have roll bars. The roll-lateral low frequency dynamics is more complex than the vertical due to there being two coupled modes. The variability between cars and the relatively complex dynamics make it impractical to generalize about the influence of lateral damping on dynamic response.

Several important low resonant responses above 2 Hz are associated with the truck mass between primary and secondary springs and the car body as a flexible structure. There are two degrees of freedom which cause two resonant responses in the range between 3 Hz and 12 Hz for all but one of the 15 cars covered herein. These resonant responses can be better understood by identifying two single-degree-of-freedom dynamic subsystems whose resonant frequencies are closely equal to the total system resonances provided. The subsystems are nearly uncoupled. The truck mass between primary and secondary springs, if treated as rigid (the truck sprung mass), has a vertical degree of freedom which yields the truck bounce resonant frequency. The car floor is assumed fixed for this subsystem. This frequency varies between 3.5 Hz and 7.5 Hz for 13 of the 15 trucks described in this report. It is relatively uncoupled from the car bounce mode, by virtue of occurring at more than 3 times the car bounce frequency. Therefore, the subsystem resonance is close to the corresponding total system resonance provided flexible car behavior is not significant at the truck bounce resonance.

In 10 of the 15 cars, the car lowest resonant frequency as a free beam in space is between 1.2 and 2.0 times higher than the the truck bounce frequency. Thus, in these cases it is coupled to the truck bounce frequency. The Italian Z1040 has a ratio greater than 2.0. For two vehicles the car frequency was unknown. The AMCOACH and Metroliner have truck bounce frequencies of about 26 Hz, and car body free beam resonances of about 7 Hz and 10 Hz, respectively, which is in the range of the other 13 car bodies. The relatively high truck bounce frequencies distinguish these vehicles from the other 13.

The Metroliner has a power transformer equal to about 10% of the car body weight sprung under the center of the car at about 4.5 Hz, which influences its low frequency dynamic behavior.

The primary vertical springing provides between 70% and 92% of the total stiffness for the truck bounce mode. Thus, a given fractional variation in the primary springing has more effect on the truck bounce resonance than the same variation in secondary springing. The primary and secondary vertical dampers work in parallel to control the truck bounce mode. For most of the trucks described, the primary vertical damping is not specified. It should be selected to supplement the secondary in sufficiently damping the truck bounce mode while not being so high as to transmit excessive high frequency vibrations.

The low frequency dynamics of some of the railcars reported is modified by the addition of a linkage which provides torsional restraint between each truck and the car body. The purpose of this spring (referred to as a roll bar) is to prevent excessive lean or lateral motion of the car in response to static or quasistatic side loads, such as occur when operating at overspeed or underspeed on curves. The excessive lean is accentuated by cars with center of gravity relatively high above the suspension, or relatively soft suspensions, since the roll moment augment due to center of gravity lateral shift becomes of major importance in adding to the lean and lateral shift on these cases. Several of the trucks have active tilt control to help prevent lean. It is not known whether or not this control influences dynamic behavior.

All the cars described have some provision for allowing truck yaw with respect to the car, as necessitated for traversing curves. In most cases frictional or hydraulical damping is included with a geometry which allows yaw without static restraining forces. In some cases the yaw occurs through springs which do offer static restoring forces. The yaw damping is necessary to control the combined yaw and lateral motion of the truck as it steers by virtue of its coned wheels. The damping should be maintained at a level sufficient to maintain stability while being low enough not to cause flanging on curves.

6. RECOMMENDATIONS

It is recommended that tests be performed on any or all of the high speed trucks included in this report or that communications be extended to the countries involved. Either method will enable the data extracted from the references to be verified, the engineering estimations where asterisks appeared in the table to be substantiated and the areas where reasonable engineering approximations could not be performed to be completed.

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APPENDIX A

Report of Inventions

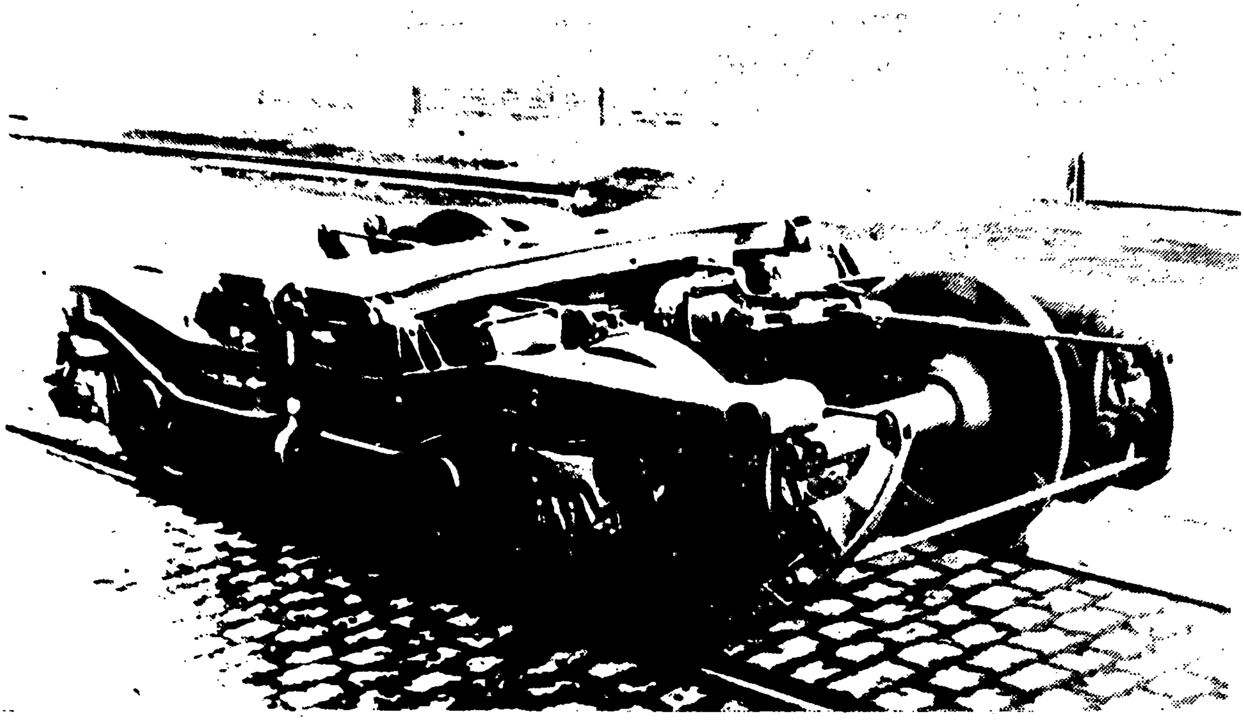
The main purpose of this project was to tabulate truck and car body data for rail vehicles traveling at speeds of 125 mph or higher. No inventions were achieved during the performance of work under the contract. However, the tabulated engineering parameters in this report can be used for modeling of rail vehicle dynamic performance which may lead to improvement of ride quality and operational safety.

APPENDIX B

Photographs of High Speed Trucks

This appendix contains photographs of the fifteen selected 125 mph high speed trucks, courtesy of these publications: Chemins de Fer, French Railway Techniques, Rail Engineering International, and Railway Gazette International.

Pictures of the Z1040 and BT10 truck are representative of them, but it is unclear from the literature if they are the actual trucks. All the other pictures contained in this appendix are the actual trucks.



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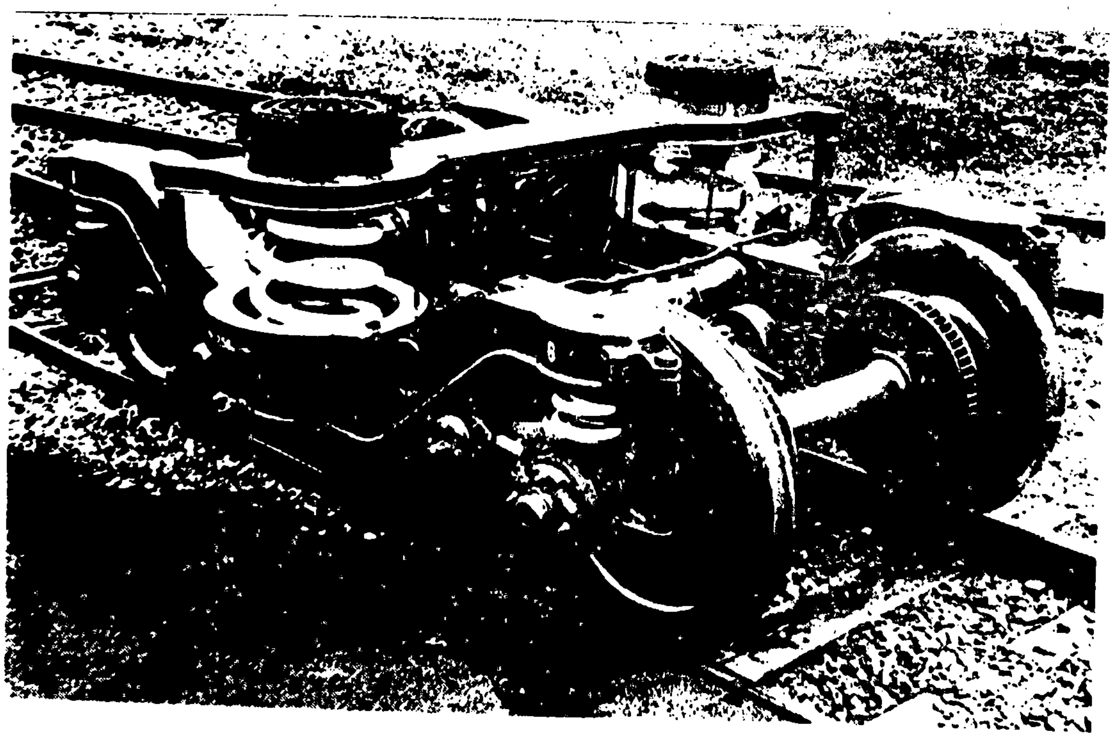

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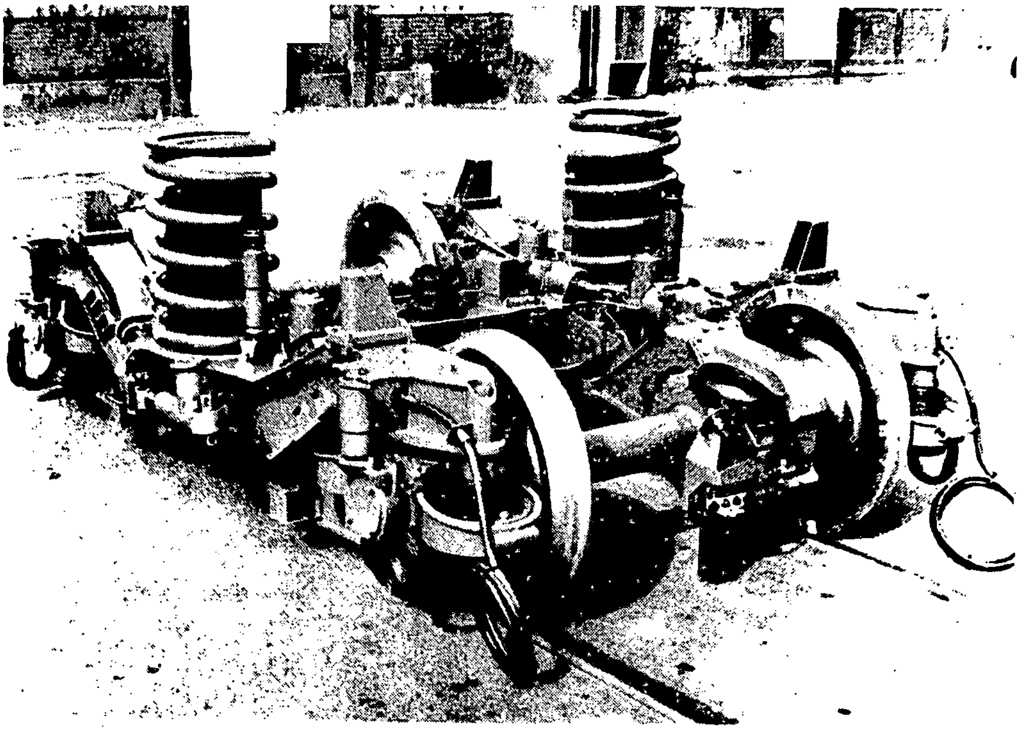

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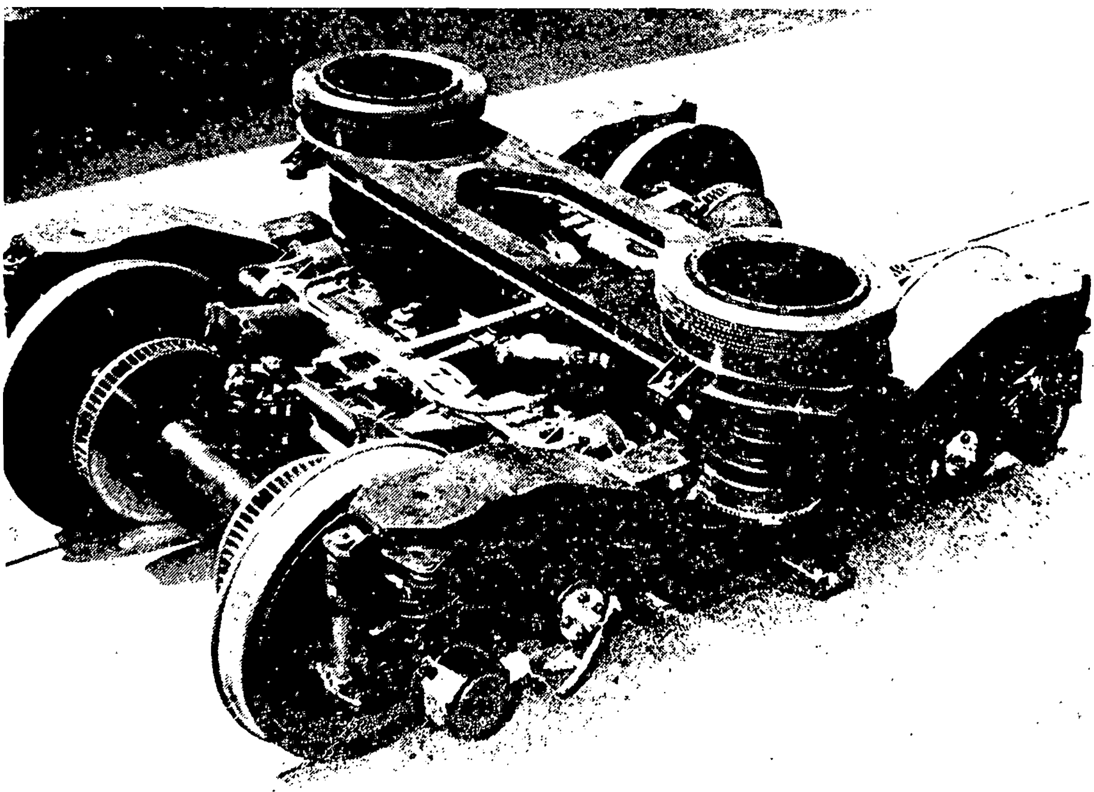

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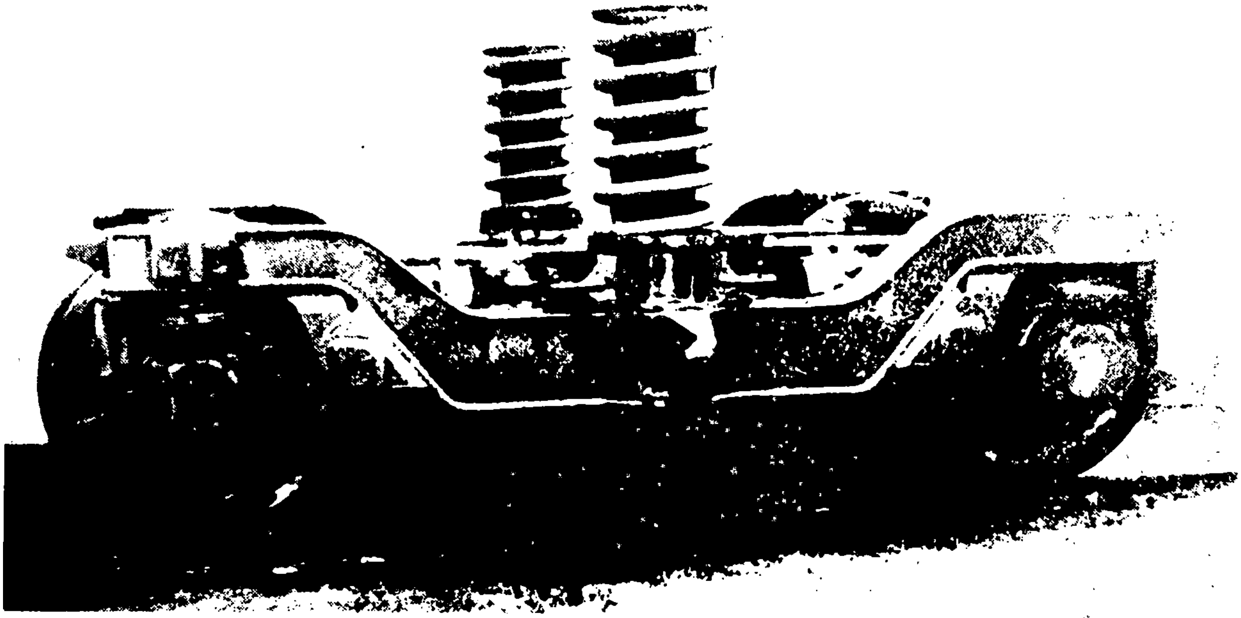

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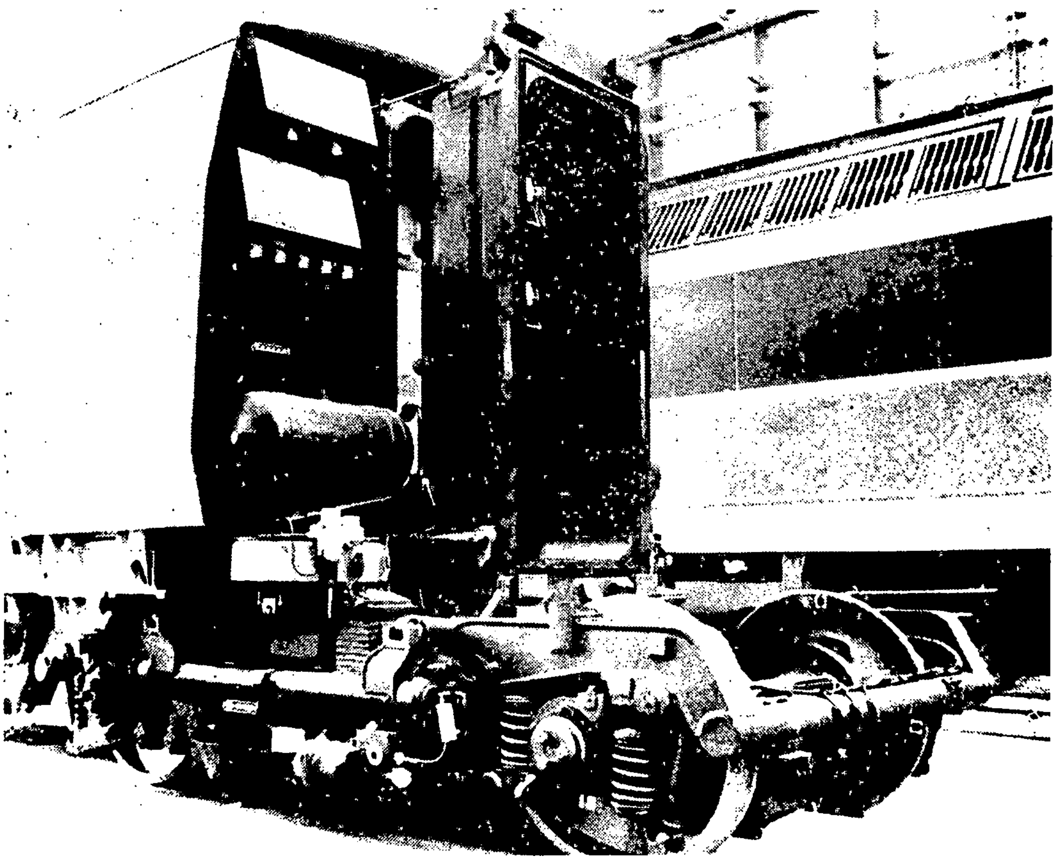

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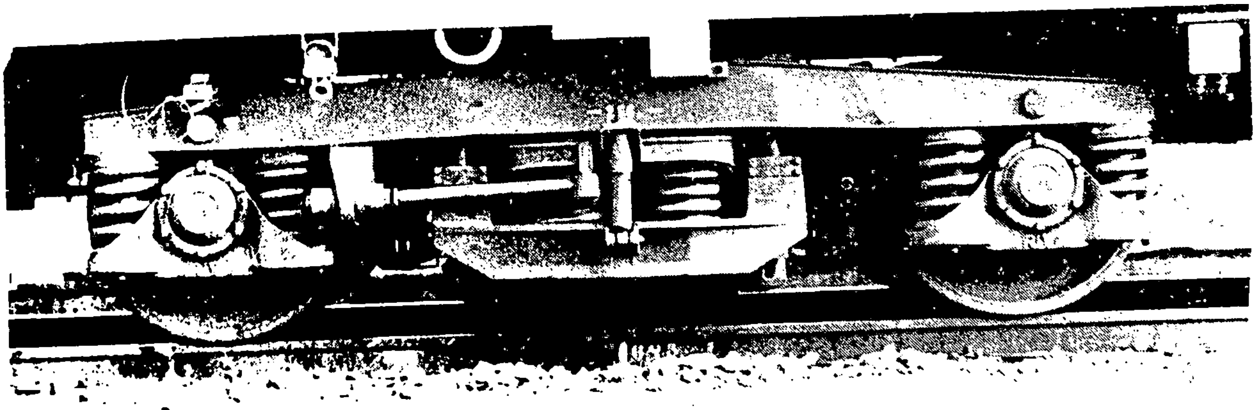

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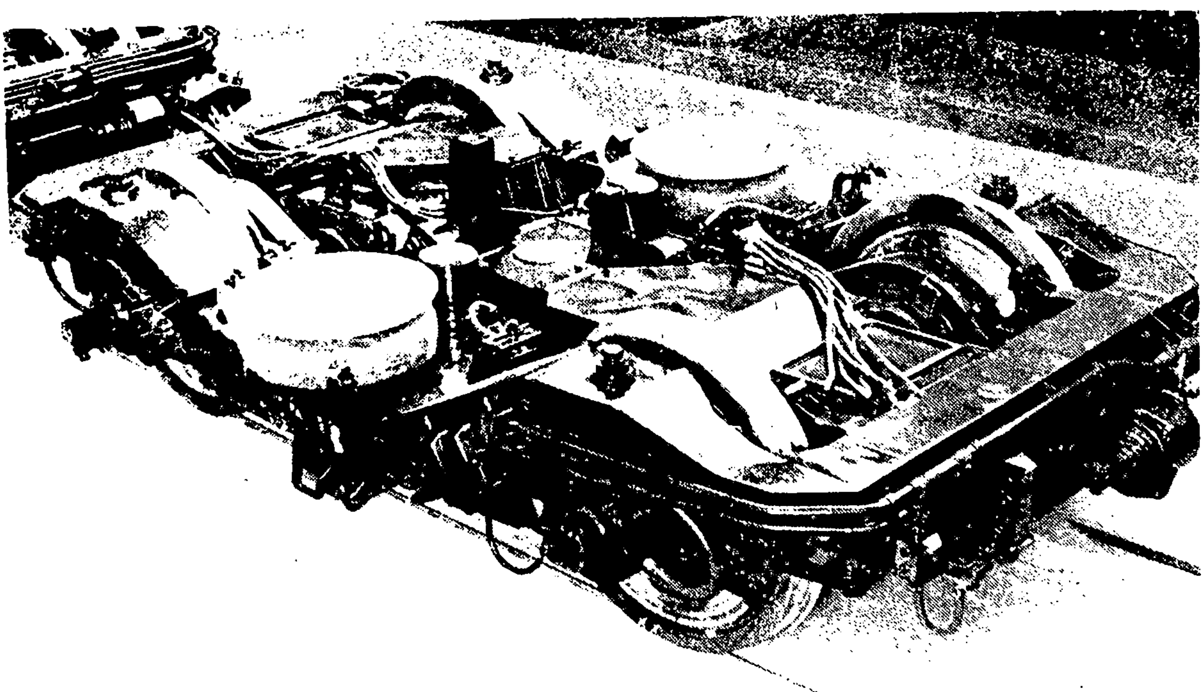

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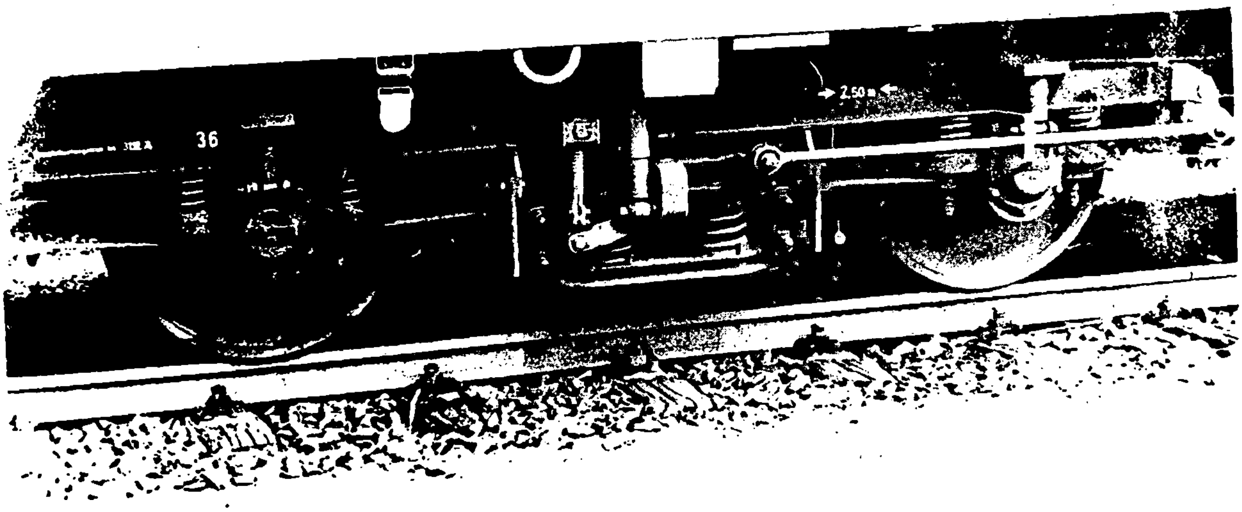

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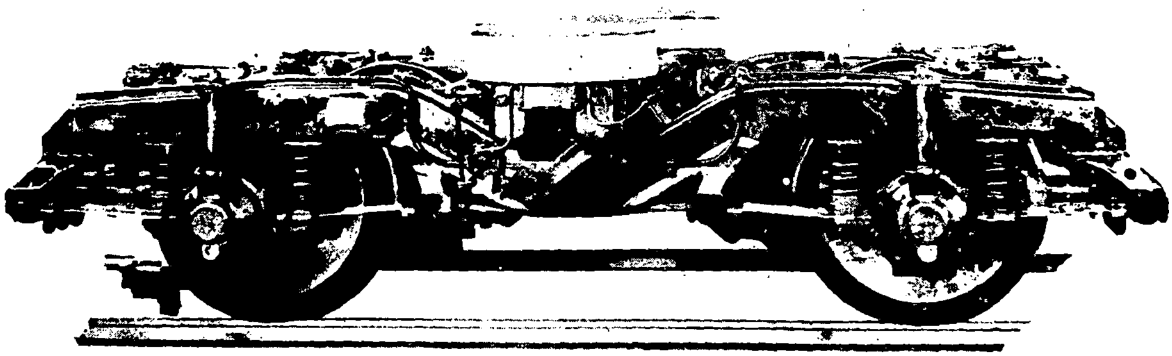

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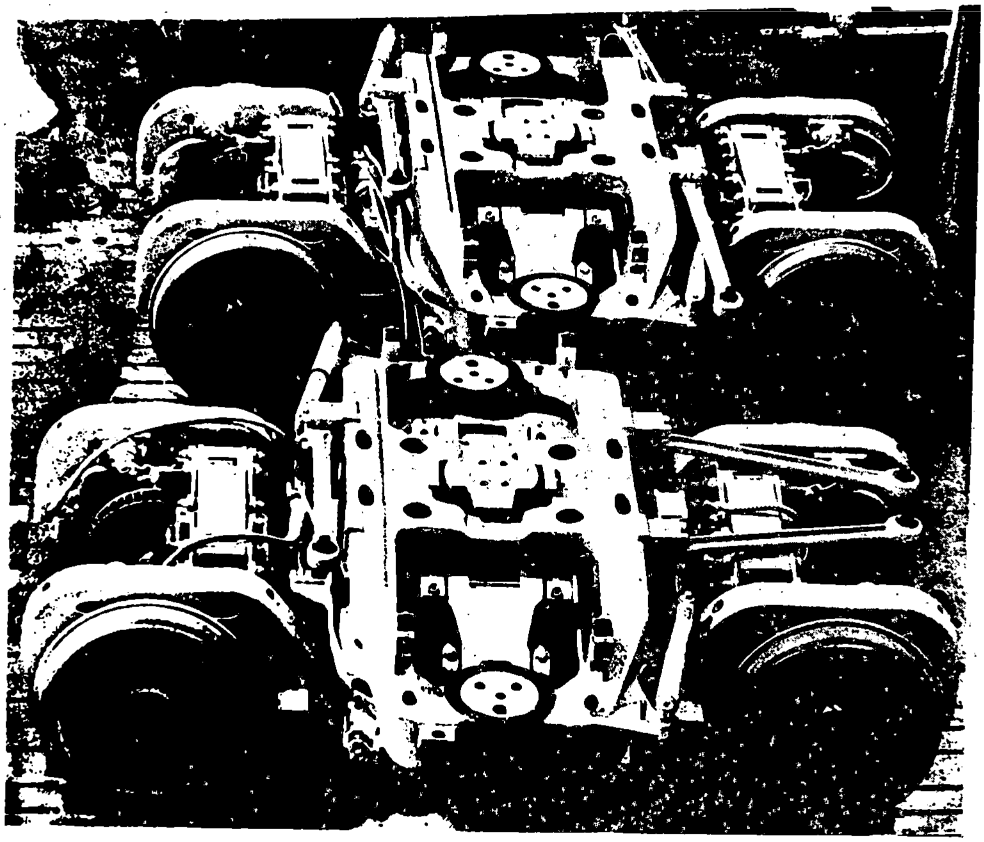

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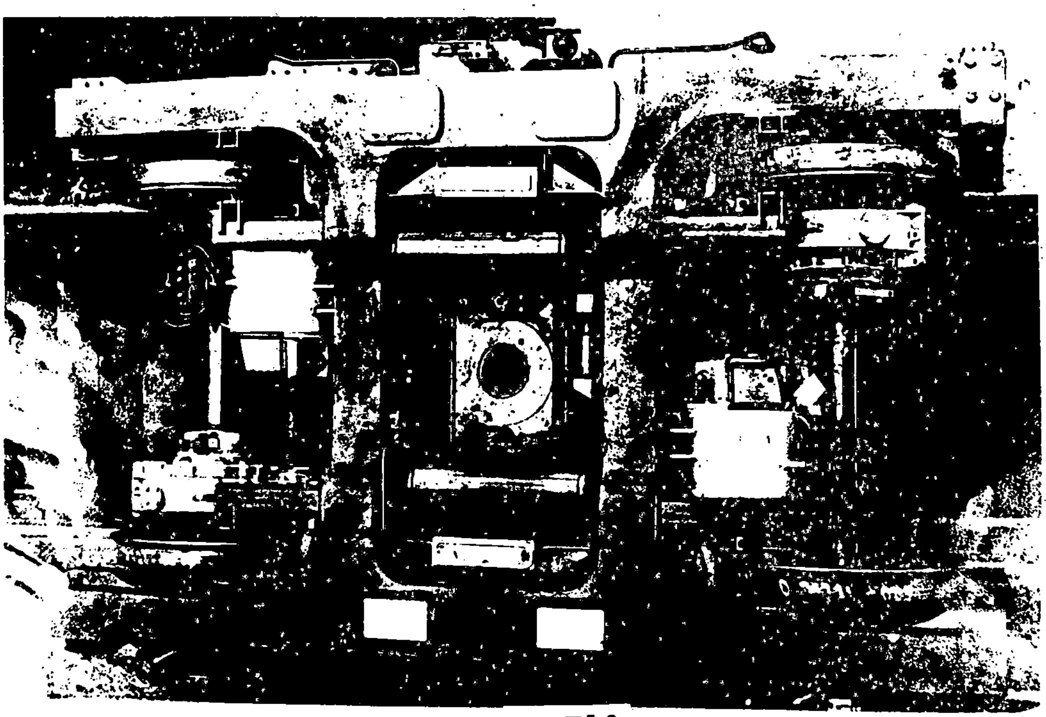

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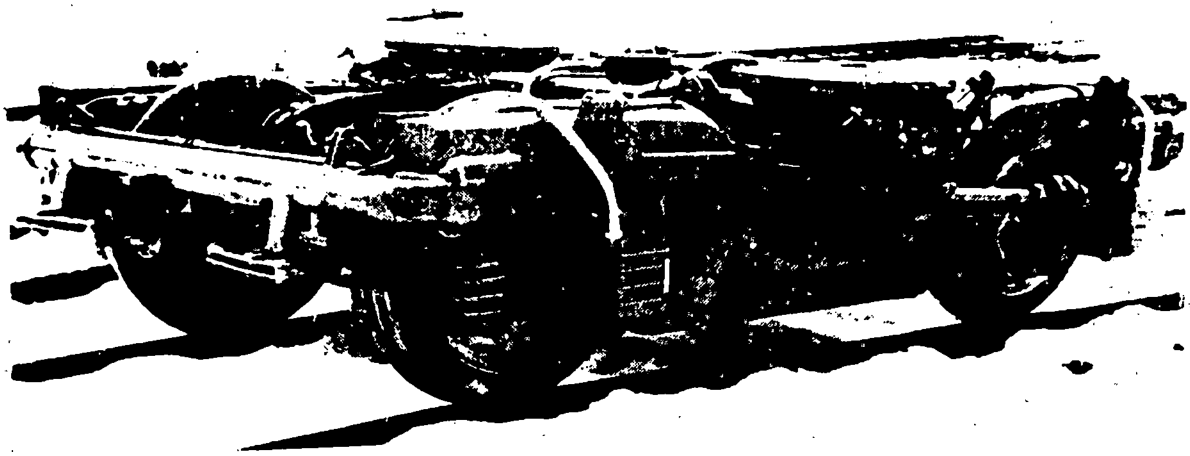

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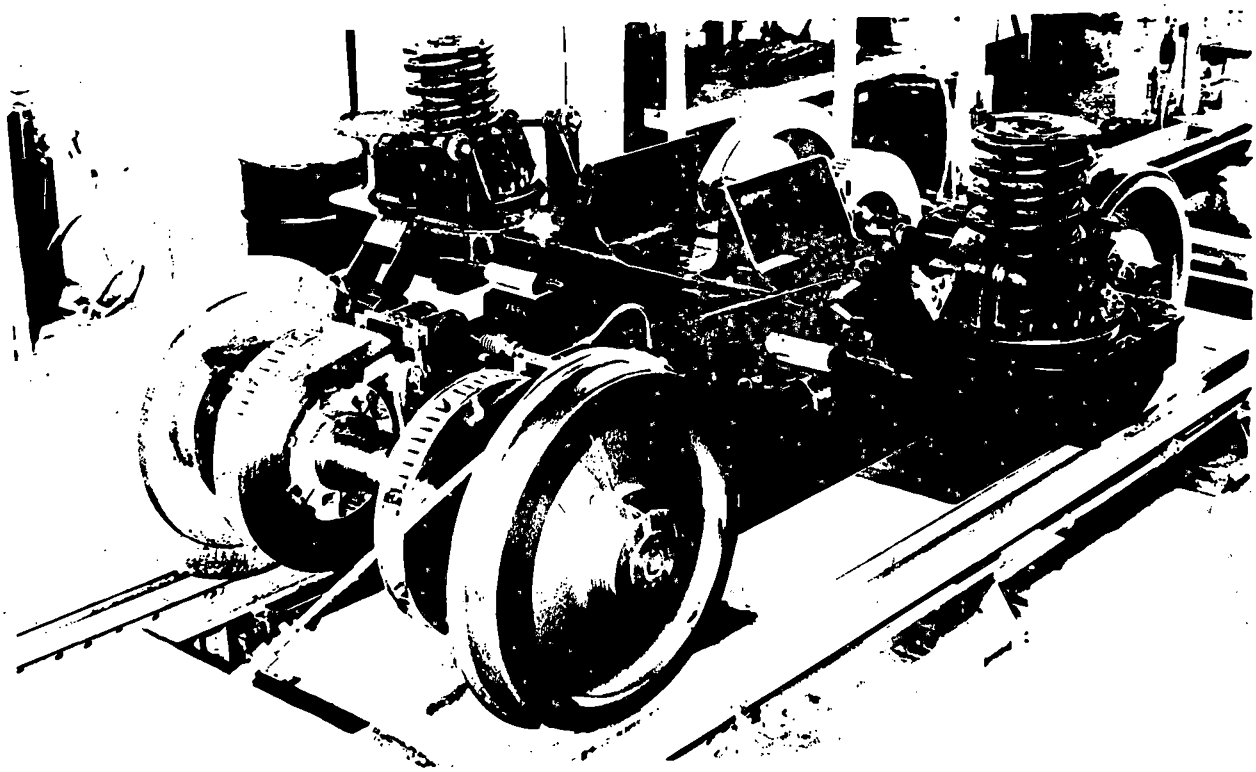

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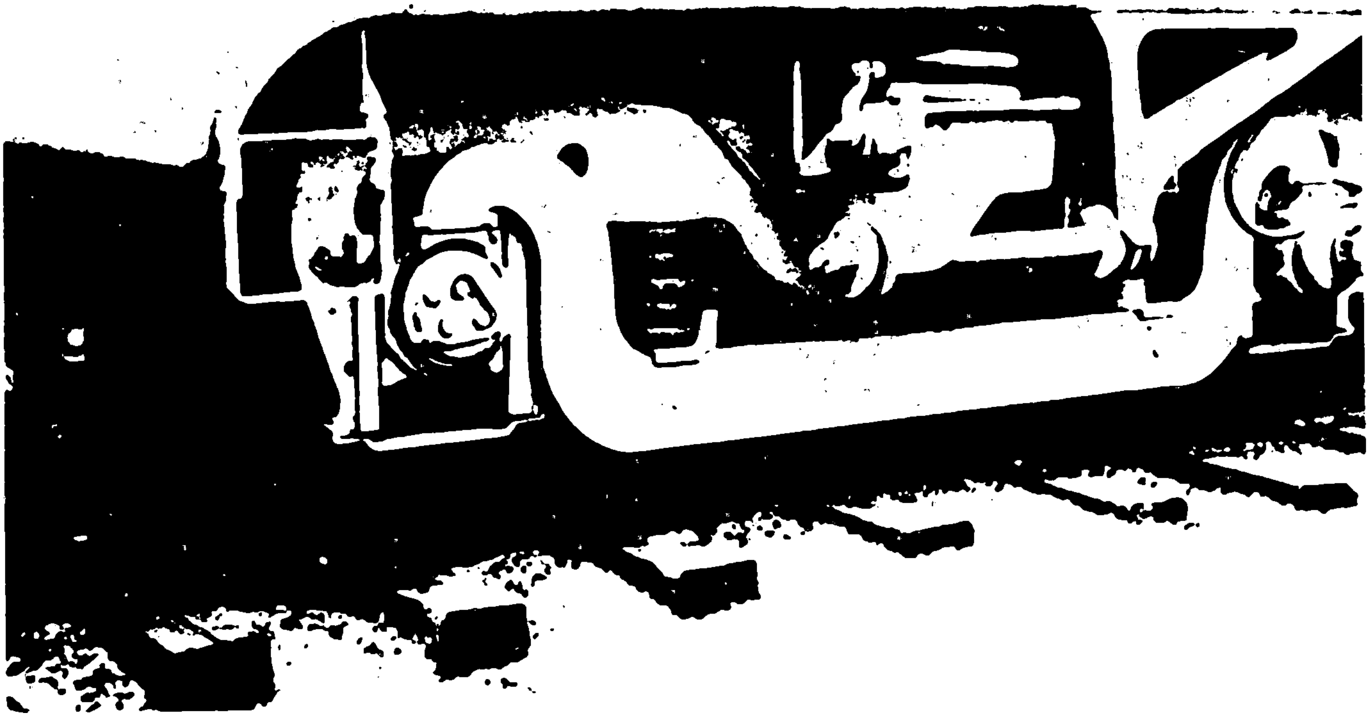

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