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The Design and Manufacture of Low-cost Motorized
Vehicles

Prepared for: the International Labour Office (ILO) and the
United Nations Centre for Human Settlements (Habitat)

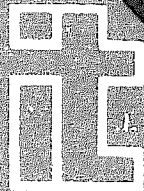
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The Design and Manufacture of Low-cost Motorized Vehicles



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THE DESIGN AND MANUFACTURE
OF LOW-COST MOTORIZED VEHICLES

The World Employment Programme (WEP) was launched by the International Labour Organisation in 1969, as the ILO's main contribution to the International Development Strategy for the Second United Nations Development Decade.

The means of action adopted by the WEP have included the following: short-term high-level advisory missions; longer-term national or regional employment teams; and a wide-ranging research programme. Through these activities the ILO has been able to help national decision-makers to reshape their policies and plans with the aim of eradicating mass poverty and unemployment.

A landmark in the development of the WEP was the World Employment Conference of 1976, which proclaimed *inter alia* that "strategies and national development plans should include as a priority objective the promotion of employment and the satisfaction of the basic needs of each country's population". The Declaration of Principles and Programme of Action adopted by the Conference will remain the cornerstone of WEP technical assistance and research activities during the 1980s.

This publication is the outcome of a WEP project.



Local-level Transport in
Developing Countries



THE DESIGN AND MANUFACTURE OF LOW-COST MOTORIZED VEHICLES

Prepared for the International Labour Office (ILO)
and the United Nations Centre for Human Settlements (Habitat)

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Preface by the ILO and UNCHS (Habitat)

At present, the majority of people in developing countries are not adequately served by transport systems. In rural areas, most people live at a considerable distance from a conventional road and, in spite of great efforts to develop rural road networks, there is little hope that an optimal road density will be reached in the foreseeable future. Moreover, even in areas where settlements have access to roads, the economic conditions do not permit a large increase in the use of conventional motorized vehicles on an extended road network.

Few people in developing countries can afford either to own or use a conventional motor vehicle, yet traditional means of transport are ignored by those responsible for the planning and development of transport in developing countries. Therefore, human portage is still the main way in which the poor move goods in many areas, and a great number of personal trips are made on foot. Generally, the inadequacies of existing transport systems are a constraint on economic and social development.

It is becoming increasingly apparent that the conventional approach to local transport development cannot respond to the transport needs of most of the low-income population. Among various measures which would change the present situation, an important one is the wide-scale promotion of efficient low-cost forms of transportation. There is a range of these, both motorized and non-motorized, found in different countries, and considerable potential for the transfer of technologies. There are also possibilities for improving traditional designs.

It is with this in mind that the ILO and UNCHS (Habitat) have initiated the preparation of a series of technical memoranda on low-cost vehicles. The purpose of these studies is to provide a simple guide to the design and manufacture of these vehicles so that (a) the technology is made known to a wide audience, including decision-makers and planners who should be aware of the potential range of proven low-cost vehicles, and (b) producers are provided with information and guidelines on the design and manufacturing procedures which can be employed in various circumstances and at different scales of production. The second technical memorandum in the series relates to low-cost motorized vehicles.

It is often suggested that apart from human- and animal-powered vehicles, the range of low-cost vehicles is limited; that the next step up the technological ladder from a donkey cart is a tractor and trailer or from a wheelbarrow, a pick-up. This technical memorandum sets out to show that there is a large variety of low-cost motorized vehicles which provide an intermediate range. They provide an additional choice when distance and speed of travel limit the practicability of human- or animal-powered transport.

The research on which this technical memorandum is based has shown that the number and diversity of low-cost motorized means of transport are far greater than previously understood. Technologies are not easily transferred, not because they are inappropriate but because of lack of knowledge and effective channels of dissemination.

This memorandum aims to bring the range of vehicles available to the attention of planners and industrial development agencies. At the same time it provides detailed technical information on their design and manufacture in order to permit small-scale producers to manufacture them efficiently.

This volume has been prepared for the ILO and UNCHS (Habitat) by Ian Barwell and Alan Smith of I.T. Transport Ltd., (United Kingdom).

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Lack of transport is one of the less obvious, but none the less important, aspects of poverty. Many rural people, and the majority of the poor, live remote from the conventional road system and are likely to continue to do so. Few are able to afford to own, or often even use, conventional motor vehicles. A similar situation frequently exists in the major cities and the smaller urban centres of developing countries, where there is a shortage of services to meet the needs for personal and goods transport of many people. In recent years increasing interest has been shown in the potential of low-cost vehicles - i.e. those which are simpler, and thus cheaper to purchase than conventional motor vehicles - to meet the need for passenger transport and the movement of goods.

The complete range of low-cost vehicles includes bicycles and attachments to increase load-carrying capacity, and animal-drawn carts. Already, efforts are being made to further the use of these means of transport, particularly of animal-drawn carts (in conjunction with the use of draught animals in agriculture) to meet the need for movement of goods in rural areas¹.

While human- and animal-powered vehicles provide low-cost, and widely affordable, means of transport, their capacity is limited in terms of the combination of range and speed of travel, and the payload that can be moved. There is, therefore, scope for the greater use of low-cost motorized vehicles which are cheaper to purchase than conventional motor vehicles. They can therefore meet transport needs which are beyond the scope of non-motorized methods, but at a lower capital cost and more labour-intensively than conventional motor vehicles. Low-cost motorized vehicles can be used to provide rural and urban transport services for the movement of people and goods.

A range of low-cost motorized vehicles is already in use in different countries. However, the geographical scope of use of different types of low-cost motorized vehicle is limited; there are examples of vehicles which are extensively and successfully used in one country but which are not found elsewhere. In some cases, this is because infrastructural conditions are not right for their wider use, but often a major reason is that the technology is not well known, or no serious effort has been directed to its dissemination or adaptation.

There are, therefore, a large number of opportunities for the transfer of low-cost motor vehicle technologies to countries or regions where they are not currently found, and for their introduction in applications where they are not presently used. There is also considerable potential for local manufacture of low-cost motorized vehicles, particularly by small- and medium-scale industries applying labour-intensive procedures. The increased use of low-cost motorized vehicles will stimulate rural and urban economic development by:

- (i) meeting transport needs which are not being addressed at

¹ See The design and manufacture of animal-drawn carts, prepared for the ILO and UNCHS, and published by Intermediate Technology Publications Ltd, London, 1986.

present by conventional motor vehicles. The use of such vehicles will reduce the continuing reliance on walking and headloading to meet movement requirements in relation to productive, economic and welfare activities;

(ii) creating employment opportunities in their production, operation, and maintenance, since the manufacture and use of low-cost motorized vehicles is inherently labour intensive.

This technical memorandum is intended to assist those who are in a position to influence the choice of public and private investment in transport facilities in developing countries. It aims to create awareness of the potential roles of low-cost motorized vehicles, and provide data on their technical requirements. Specifically, the purposes of the book are:

1. To provide public planners and industrial development agencies with information on the availability and applications of low-cost motorized vehicles and on the potential for, and impact of, their wider use.
2. To provide small-scale producers in developing countries with technical information on the design and manufacture of low-cost motorized vehicles which can be produced locally and are a viable alternative to capital-intensive technologies originating from industrialized countries.

1.2 SCOPE

The category 'low-cost motorized vehicles' includes a wide range of different types. In order to provide information in the most useful form, it has therefore been necessary to limit the scope of this book. In defining the technical content, the following guidelines have been adopted:

1. The focus is on 'utilitarian' load carriers for moving significant quantities of goods or several passengers. It is these which have the greatest potential to meet basic transport requirements in developing countries. Therefore the book does not include vehicles intended primarily for the personal transport of the owner, perhaps accompanied by a passenger or a limited quantity of goods. Nor does it include information on vehicles which are complex, or designed for specialized applications. Rather the emphasis is on simple, robust, durable, general-purpose vehicles.
2. The cheapest types of motorized vehicle are those based on the attachment of a motor to a bicycle. These have been excluded for two reasons:
 - (i) there is a limit to what can be achieved with this type of vehicle - in terms of payload, durability and ability to operate on rough roads and tracks -- without upgrading the vehicle to motor cycle technology;
 - (ii) it is considered preferable to cover this type of vehicle in a future technical publication concerned with pedalled vehicles.

3. Vehicles at the top end of the low cost motorized range - such as the jeepneys of the Philippines and the Asian Utility Vehicles (AUV) found in several countries - have been excluded. These are essentially slightly simpler versions of conventional motor vehicle technology, and are considered to be too close in price to these vehicles to be truly 'low-cost'.

In terms of manufacture, low-cost motorized vehicles fall into two categories:

(i) those which can be designed/adapted and manufactured 'independently' by small or medium-scale producers in developing countries;

(ii) those which require some form of collaboration with the source of the technology in another country. Some, but not all, of these involve a fairly large-scale investment if they are to be manufactured (rather than assembled) locally.

The main technical chapters concentrate on vehicles in the first category, but there is also a compendium of information on vehicles in the second.

The range of technologies covered, described in more detail in Chapter 2, are:

- trailer for standard motor cycle;
- sidecar for standard motor cycle;
- four-wheeled conversion of standard motor cycle;
- three-wheeled vehicle based on motor cycle technology;
- three-wheeled vehicle using small diesel engine;
- four-wheeled vehicle using small diesel engine;
- trailer for single-axle tractor.

1.3 HOW TO USE THIS BOOK

The contents are structured as follows:

Chapter 2 provides an assessment of the operating and cost characteristics, likely applications and manufacturing implications of the different types of vehicle described.

Chapters 3,4,5 and 6 provide the detailed technical design information on the different types of vehicle which are suitable for 'independent' manufacture in developing countries. They are complemented by six annexes which provide the basic data on key technical aspects.

Chapter 7 provides advice on technical and economic considerations in the manufacture of low-cost motorized vehicles, and presents a procedure for calculating production costs and sales prices.

Chapter 8 provides information on low-cost motorized vehicles whose acquisition requires some form of collaboration with the source of the technology. The entries are selective, concentrating on those vehicles which are considered most relevant to conditions in developing countries.

Thus, for planners and decision-makers wishing to identify or select low-cost motorized vehicles to meet local transport needs, or as the basis for establishing local industries, the key information is contained in Chapter 2. Reading Chapters 3-8 is also recommended to provide further background information on manufacturing implications and the most suitable mechanisms for making the vehicles available in the country.

For manufacturing industries interested in developing and producing low-cost motor vehicles locally, Chapter 2 again provides the starting-point, in identifying the appropriate vehicle options on which to concentrate. The relevant technical chapter, together with the annexes, then provides the information to prepare a specification of the vehicle appropriate to local conditions. Chapter 7 should also be studied carefully as a source of advice on the most effective production engineering and management procedures.

Chapter 8 provides the basic data for organizations wishing to identify sources of commercially available technology for vehicles they have selected as being appropriate to local conditions.

2.1 DESCRIPTION OF VEHICLES

Eight different types of low-cost motorized vehicle are covered in this publication and each is described briefly below.

The first three vehicle options are all attachments to standard motor cycles. Attention is concentrated on the attachments, on the basis that motor cycles are readily available in most developing countries, either as imports or locally manufactured items. All the attachments are suitable for 'independent' local production by small- or medium-scale industries and technical details are presented in Chapter 3. However, there are also commercially available technologies for the first two attachments.

1. Motor cycle and trailer

This consists of a two-wheeled, load-carrying trailer attached to the rear of the motor cycle (Figure 2.1) by means of a hitch which allows it to be connected and disconnected quickly and easily. Motor cycle trailers are already used to a limited extent in certain developing countries, most notably in francophone areas, but there is considerable potential for their wider use.

2. Motor cycle and sidecar

This consists of a single-wheeled, load-carrying attachment rigidly fixed to the side of a motor cycle (Figure 2.2). These are extensively used in the Philippines, where there are over 150,000 in operation. They provide efficient, economical short-haul transport services in a variety of conditions and for a range of applications. The motor cycle and sidecar is not used in the same way anywhere else in the developing world, and there is great potential for the transfer of the technology to other countries.

3. Four-wheeled conversion of motor cycle

This consists of a chassis and load-carrying body with a two-wheeled axle which is securely attached to the motor cycle so that the load is carried on either side of, and behind, the motor cycle (Figure 2.3). This type of vehicle is finding increasing use for short-haul movement of loads in the Philippines, as an evolution from the popular motor cycle and sidecar. At present the vehicle is unique to the Philippines but it also has potential for use in many other developing countries.

The next four options all involve the production of a complete vehicle. However, three make use of some standard motor vehicle components and the other is based on a motor cycle which is permanently modified to produce a load-carrying vehicle.

4. Motor cycle based three-wheeled vehicle

This consists of a standard motor cycle which is converted, by means of an extended chassis, the attachment of a two-wheeled rear axle

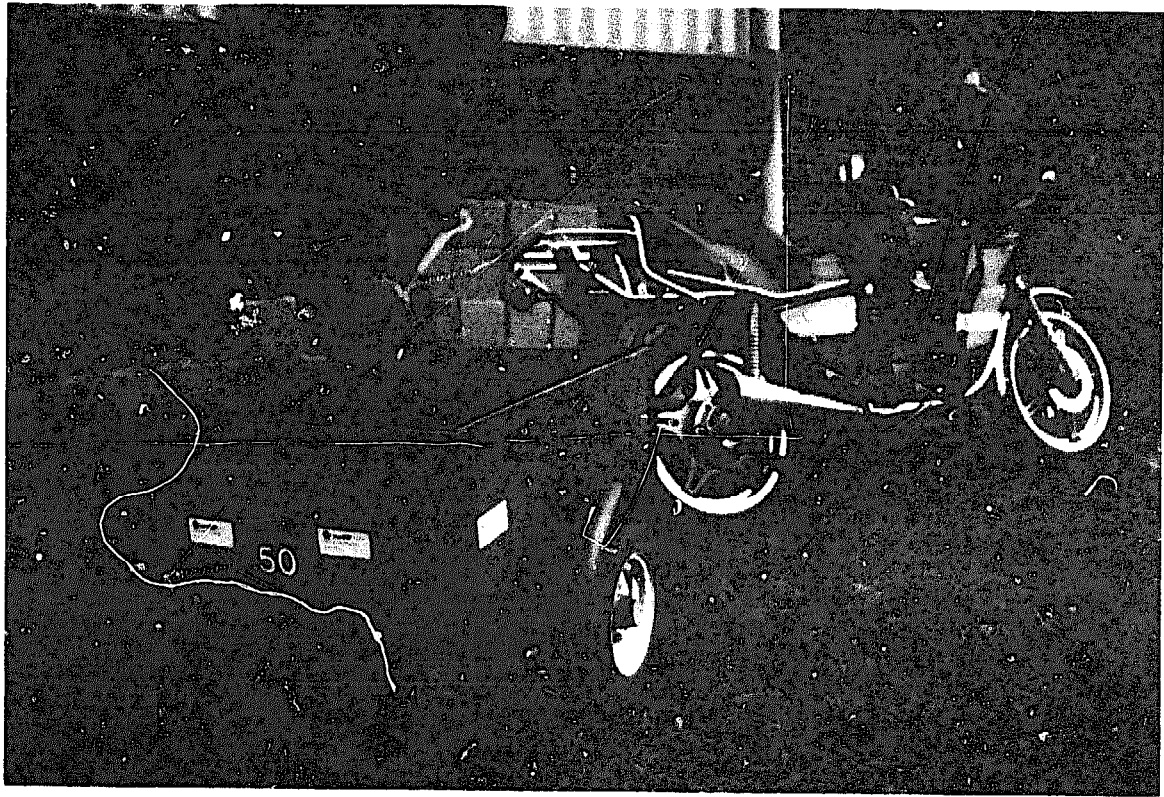


Fig. 2.1 Motor cycle and trailer

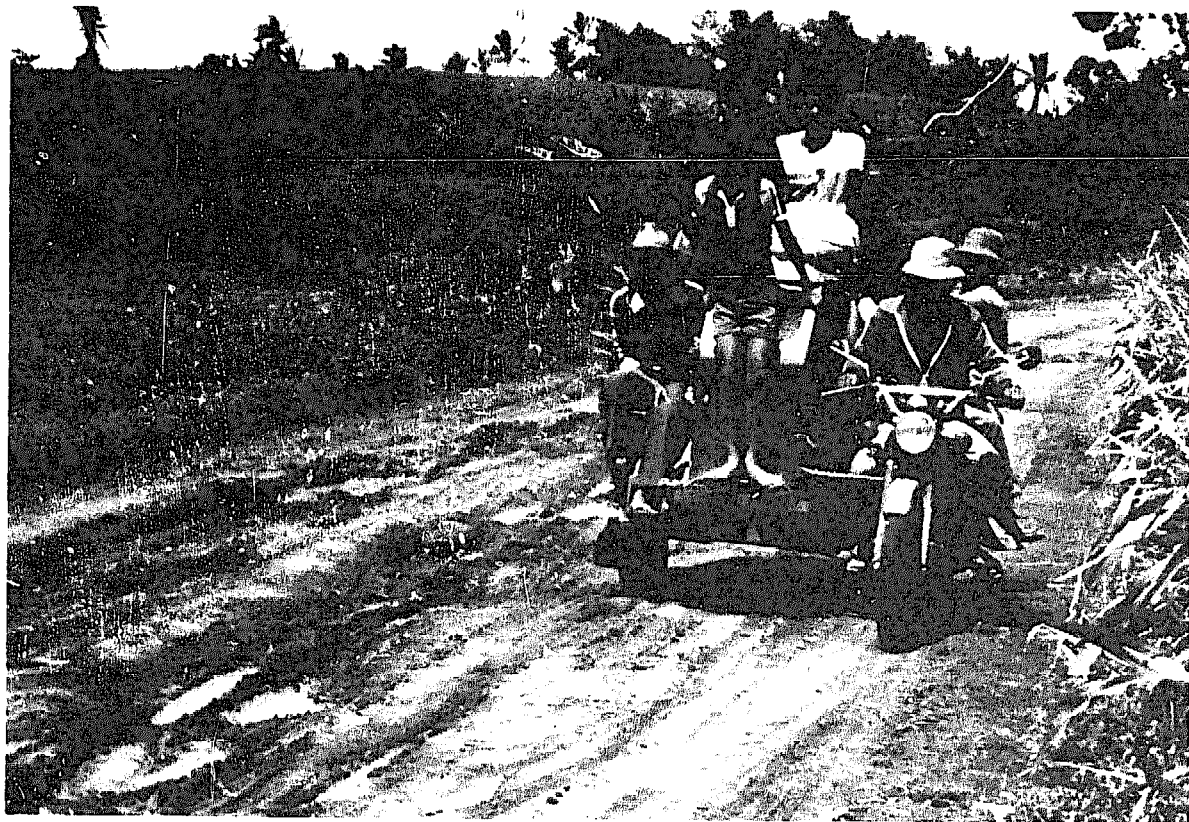


Fig. 2.2 Motor cycle and sidecar



Fig. 2.3 Four-wheeled conversion of motor cycle

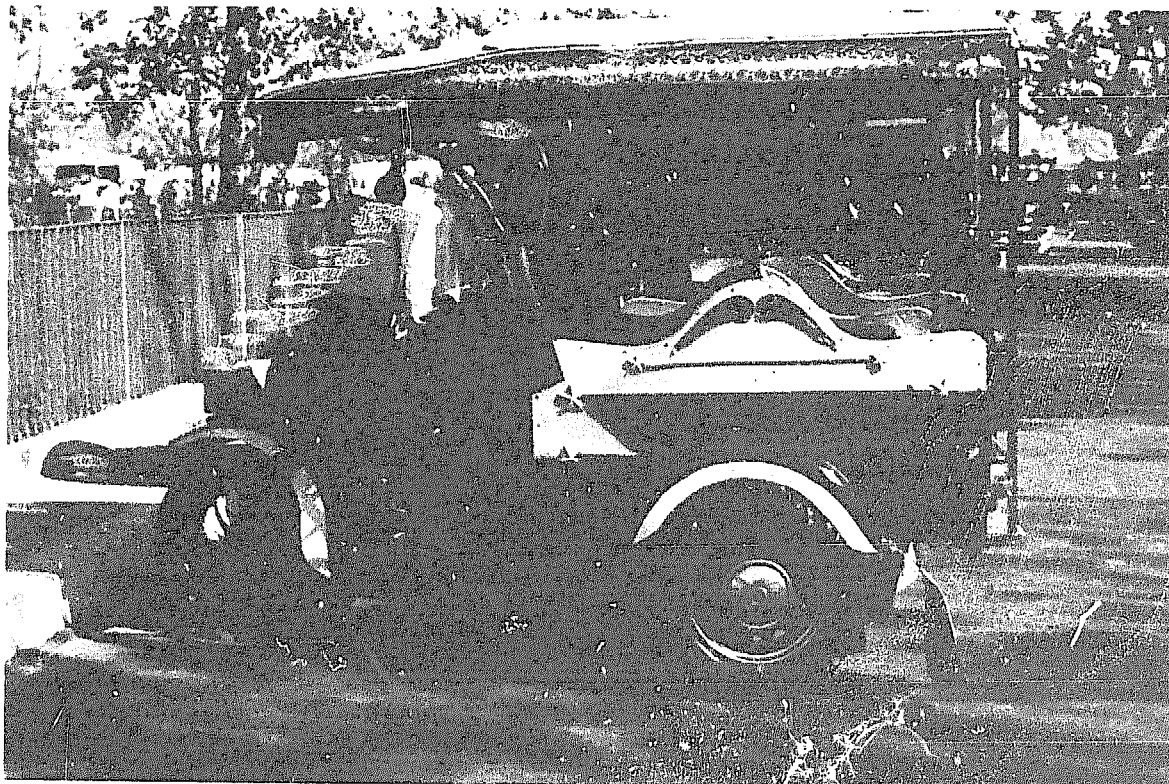


Fig. 2.4 Motor cycle based three-wheeled vehicle

and the construction of bodywork behind the driver, to provide a permanent, three-wheeled load-carrying vehicle (Figure 2.4). This type of vehicle is suitable for 'independent' production by a developing country manufacturer, and its technical details are presented in Chapter 4. These vehicles are used in limited numbers in several countries but there is potential for wider use, and for introduction in places where they are not found at present.

5. Small diesel-engined three-wheeled vehicle

This vehicle is powered by a single-cylinder diesel engine and consists of a purpose-built chassis with a single, steered wheel at the front, two rear wheels, and load container situated behind the driver (Figure 2.5). This type of vehicle is suitable for 'independent' production by a developing country manufacturer, and its technical details are presented in Chapter 4. Vehicles of this type are found to a limited extent in a few developing countries, but are widely used by small farmers in some Mediterranean regions. There is considerable potential for developing country use, particularly in areas where the owner can also utilize the diesel engine for other activities, such as driving a water pump or crop-processing equipment.

6. Commercially produced three-wheeled vehicles

These are purpose-built three-wheeled vehicles, usually with one wheel at the front and two at the rear, often based on scooter or motor cycle technology and components (Figure 2.6). There are existing manufacturers in some developed and certain Asian, countries, most notably in India. Supply of these vehicles is dependent on some form of collaboration with the source of the technology and examples are given in Chapter 8. They are extensively used in some Asian countries, primarily for urban transport but are rarely found in Africa where there is considerable potential for their wider use.

7. Small diesel-engined four-wheeled vehicle

This consists of a simple four-wheeled chassis with load-carrying bodywork fitted behind the driver, driven by a small (usually single-cylinder) diesel engine (Figure 2.7). This type of vehicle is suitable for 'independent' production by a developing country manufacturer, using components from scrap conventional motor vehicles, and its technical details are presented in Chapter 5. However, commercially available technologies are also available, and examples are presented in Chapter 8. These vehicles have evolved in The Republic of Korea and Thailand where they now enjoy widespread use. There is potential for the introduction of the technology in developing countries where there is a ready supply of scrap motor vehicles.

The last vehicle option is an attachment to a standard single-axle tractor (also known as a power-tiller or two-wheeled tractor). This review concentrates on the attachment, on the basis that single-axle tractors are readily available in many developing countries, either as imports or as locally manufactured items.

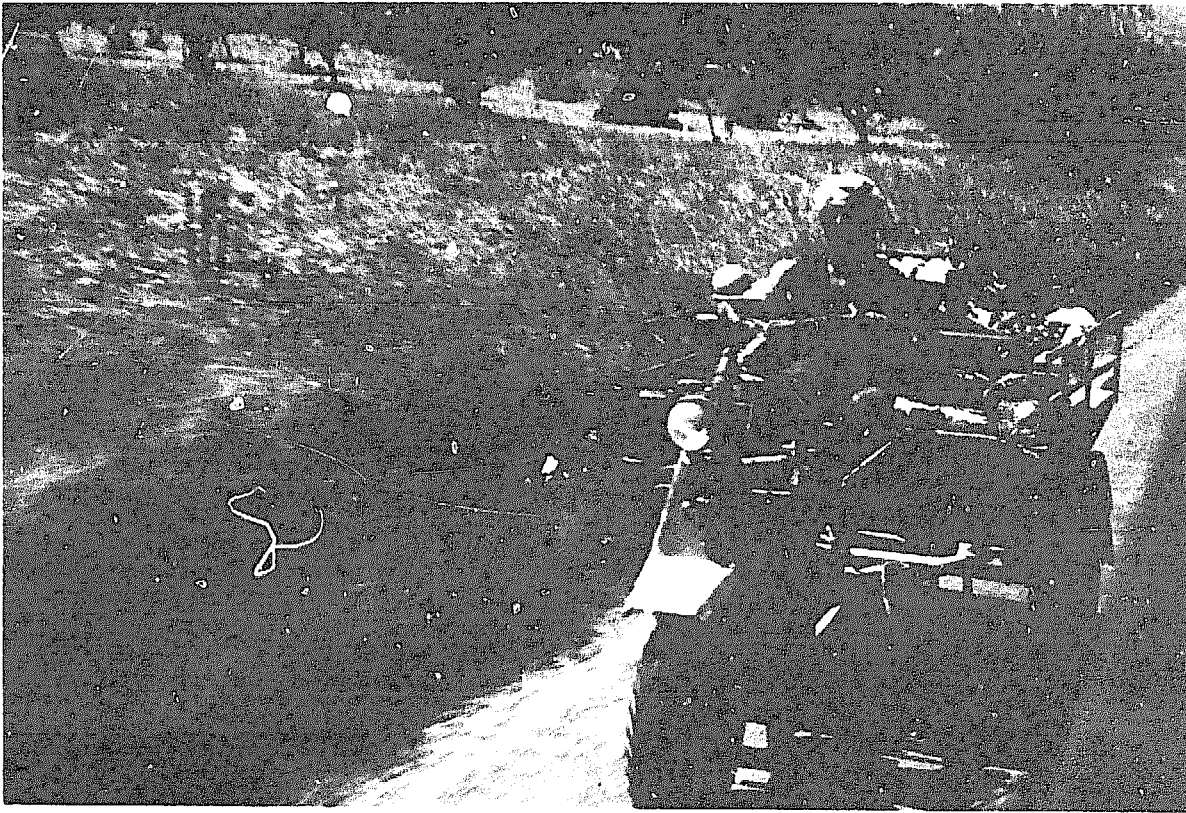


Fig. 2.5 Diesel-engined three-wheeled vehicle



Fig. 2.6 Commercially produced three-wheeled vehicle



Fig. 2.7 Small-engine four-wheeled vehicle

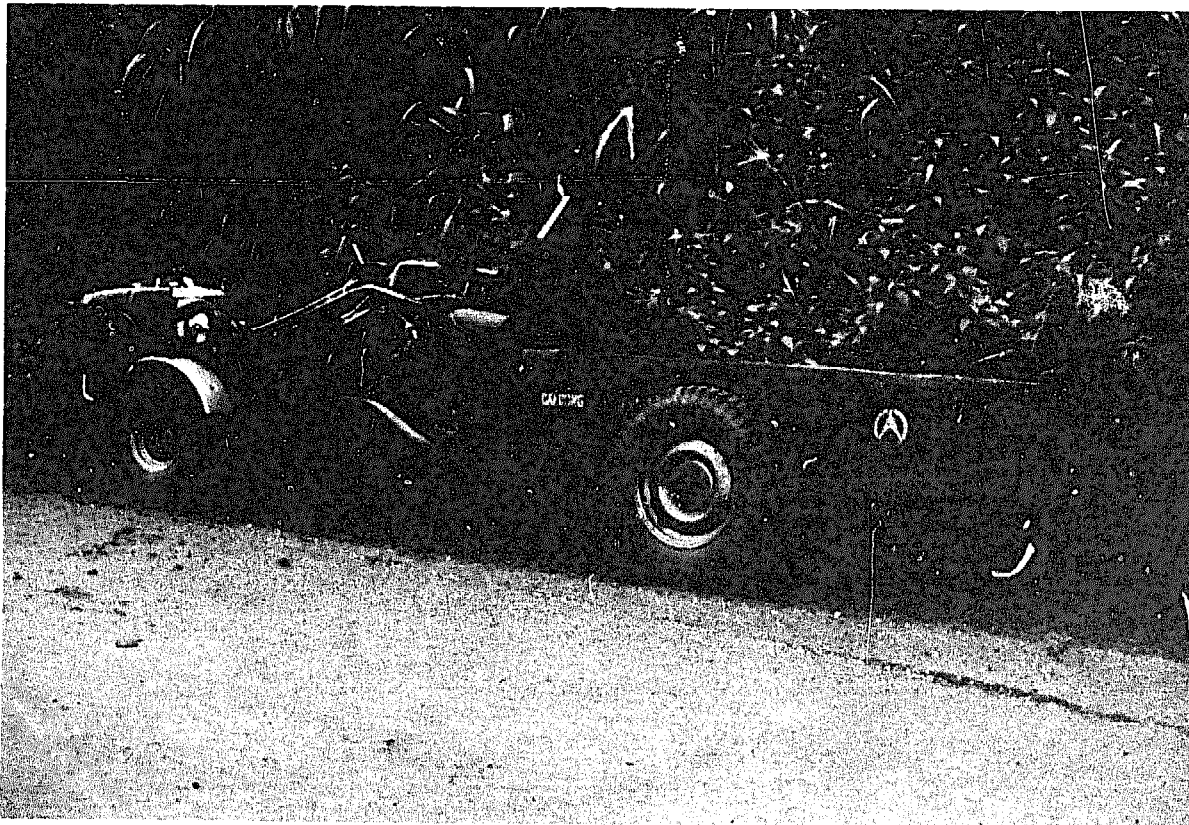


Fig. 2.8 Single-axle tractor and trailer

8. Single-axle tractor and trailer

This consists of a two-wheeled, load-carrying trailer attached to the rear of the single-axle tractor (Figure 2.8) by means of a hitch which allows it to be connected and disconnected quickly and easily. Trailers are already used in areas where single-axle tractors are a popular and economically efficient piece of agricultural equipment. However, there is potential for their wider application as the use of single-axle tractors increases, and for greater emphasis on local manufacture by small- or medium-scale industries. Technologies are commercially available, but trailers are well suited to 'independent' production in developing countries and full technical details are presented in Chapter 6.

2.2 ASSESSMENT OF VEHICLE CHARACTERISTICS

Typical dimensions and performance characteristics of the different vehicles are summarized in Table 2.1. No information on the purchase cost of the vehicles is included in this table since the large variations between different countries make it very difficult to present 'universal' costs. However, in the descriptions which follow an indication of the likely cost of each vehicle, which can be applied to particular local circumstances, is given.

Each type of low-cost motorized vehicle is assessed below:

1. Motor cycle and trailer

Applications The trailer should be used for transport of goods only, since it is considered unsafe to carry passengers in a vehicle towed behind a motor cycle. Motor cycles with trailers are suitable for both rural and urban use. A major advantage of the trailer is that, because it can quickly be connected and disconnected, it is suitable for use by existing owners of motor cycles, and does not detract from the convenience of the original vehicle for personal transport. It therefore has considerable potential for ownership by individuals to meet their personal transport needs. In rural areas, such owners are also likely to make the vehicle available to other users on a 'for hire' basis. It also has potential for the provision of goods delivery services in urban areas.

Transport capacity The useful payload that can be moved by the trailer depends on the power output of the motor cycle. For lightweight 50cc motor cycles, the payload should be restricted to about 100kg. For 100-125cc motor cycles a payload of up to about 250kg is appropriate. In some developing country situations, motor cycle trailers are used to carry over double these loads but in most circumstances such high loads will result in a significant reduction in safety. Travel speeds will be somewhat slower with a loaded trailer, because the extra weight being moved will reduce the performance of the motor cycle. The range of travel is essentially that of a motor cycle.

Infrastructure requirements A motor cycle and trailer can be used on earth roads and rough tracks of sufficient width to allow the vehicle to pass. However it is not suitable for use on routes consisting of two parallel wheel tracks separated by

Table 2.1: Typical dimensions and performance characteristics of different types of low-cost motorized vehicles.

	Motor cycle and trailer	Motor cycle and sidecar	Motor cycle based 4-wheeler	Motor cycle based 3-wheeler	Diesel engined 3-wheeler	Diesel engined 4-wheeler	Single axle tractor trailer
Wheel base	-	1.1-1.4m	1.5-2.0m	1.5-1.9m	1.5-3.3m	2.0-3.6m	-
Track	0.7-1.0m	1.1-1.25m	1.2-1.5m	1.0-1.2m	1.2-1.5m	1.2-1.5m	1.2-1.5m
Load capacity	100-500kg	200-500kg or 2-8 passengers	400-500kg or 4-8 passengers	500kg or 3-8 passengers	750-2000kg	1500-2000kg	500-1250kg
Minimum infrastructure requirements	earth road but not a 'two-track' road ¹	earth road	surfaced road	earth road, but not a 'two-track' road ^{1,2}	earth road	earth road	earth road
Cruising speed	40-55km/h	35-50km/h	30-45km/h	35-50km/h	20-25km/h	30-50km/h	12-15km/h
Climbable gradient (fully laden)	10-15%	10-15%	5-10%	10-15%	15-20% 5-10% (front- wheel drive)	15-20%	5-10%

1 A 'two-track' road is one consisting of two parallel wheel tracks separated by a grassed central section.

2 Small-wheeled versions restricted to paved roads.

a grassed central section since the motor cycle must travel along the central section. In certain developing countries wooden bridges that have two parallel wheel tracks separated by widely spaced cross members are common. To negotiate this type of bridge a trailer must be detached from the motor cycle and pushed across by hand. In areas where these bridges are common the use of motor cycle trailers is, therefore, severely constrained. They can be operated in steep terrain, but payload sharply decreases with increasing gradient.

Costs Typically, the purchase cost of the trailer will be 30 to 40 per cent of that of the motor cycle.

Operating costs on a per km basis will be somewhat higher than for the solo motor cycle because of:

- increased depreciation;
- increased fuel consumption;
- increased maintenance resulting from extra strain imposed on the motor cycle.

Manufacture The manufacture of a trailer is relatively simple, the essential requirements being basic metal fabrication, machining, and bodywork construction skills and facilities. The trailer is suitable for production by small, well-equipped metal workshops.

2. Motor cycle and sidecar

Applications The motor cycle and sidecar can be used for the short-haul movement of passengers, goods or, most typically, a combination of the two. A motor cycle and sidecar may be bought by an individual for personal use but, based on evidence from the Philippines, the most important application is to provide transport services. In the large cities they provide flexible route feeder services for passengers, operating from fixed stations, and linking into major routes where conventional public transport services operate. In smaller urban centres they provide extensive fixed-route passenger services, again from a fixed station. However, perhaps of most interest is their transport role in rural areas. They provide an extensive network of regular, combined passenger and goods services, linking villages to markets and other local centres. They thus constitute the first stage of the rural transport system, out of the village to local centres on the secondary or highway network where conventional motor vehicles operate. Therefore a key feature of the motor cycle and sidecar is the capability of the same basic vehicle design to be used for a variety of rural and urban services. However, for rural use the vehicle must be strengthened to withstand operation on rough surfaces with heavy loads.

Transport capacity In the Philippines these vehicles are usually based on 100cc or 125cc motor cycles. In urban applications they carry 2-4 passengers, depending on the bodywork. In rural areas the motor cycle and sidecar typically carries 6-8 passengers or combined loads of up to about 500kg.

The range of travel is essentially that of a motor cycle. For rural and rural-urban trips services are typically provided

over a range of up to 25km.

In urban situations the vehicle has sufficient performance to maintain pace with the normal flow of traffic. On poor rural roads travel speeds are reduced, constrained primarily by route conditions.

Infrastructure requirements A major advantage of the motor cycle and sidecar is its ability to operate on rough or muddy tracks. This capability results from the 'two-wheel track' configuration, the high ground clearance, the large diameter wheels and good traction. In the Philippines motor cycles and sidecars operate regularly on routes considered too poor for use by conventional motor vehicles. They can be operated in steep terrain but payload decreases with increasing gradient.

Costs The addition of a sidecar increases the initial cost of the motor cycle by about 50 per cent.

Operating costs are also increased and, based on Philippine data, are slightly higher than for conventional light commercial vehicles on a per tonne-km basis. However because of their low investment cost they provide economic, regular rural transport services in situations where there is insufficient demand to justify the regular operation of a larger motor vehicle.

Manufacture The manufacture of a sidecar is relatively simple, the essential requirements being basic metal fabrication, machining and bodywork construction skills and facilities. The sidecar is suitable for production by small, but well-equipped, metal workshops.

3. Four-wheeled conversion of motor cycle

Applications Because of its unusual configuration this vehicle is unsuitable for use on rough roads and is therefore restricted to paved roads. It thus lacks the flexibility of the motor cycle and sidecar, but does provide greater load space for the carriage of passengers and goods. Its major applications are goods delivery and collection, and the provision of similar urban passenger services to those offered by motor cycles and sidecars.

Transport capacity The vehicle has a similar range of travel to a motor cycle but is normally restricted to operation within urban areas. Speed of travel is somewhat slower than a motor cycle, but in urban operation the vehicle can maintain pace with the normal traffic flow. When based on a 125cc motor cycle the payload capacity is 400-500kg of goods or up to eight adult passengers.

Infrastructure requirements The vehicle is restricted to use on surfaced roads. It can operate on steep gradients, but with a substantially reduced payload.

Costs The addition of the four-wheeled conversion increases the cost of the motor cycle by 75 to 100 per cent.

Operating costs also increase and, based on Philippine evidence, are slightly higher, on a per tonne-km basis, than a

conventional light commercial vehicle. Because of the low investment cost, these vehicles can be operated successfully - for local goods delivery and collection, or for urban passenger services - in situations where there is insufficient demand to justify a larger vehicle.

Manufacture The manufacture of a four-wheeled conversion is relatively simple, the essential requirements being basic metal fabrication, machining, and bodywork construction skills and facilities. It is suitable for production by small, well-equipped metal workshops.

4. Motor cycle based and commercially produced three-wheeled vehicles.

These two types of vehicle are considered together because their transport characteristics are essentially similar.

Applications These vehicles can be used to transport passengers or goods, depending on the type of bodywork fitted. They are most commonly used in urban areas to provide a variety of flexible or fixed-route passenger services that complement those offered by conventional buses or taxis. They are also used for urban delivery and collection of goods. They would not normally be purchased by individuals to meet personal and family transport needs. In comparison with the attachments to standard motor cycles, described earlier, they have the advantage of being purpose-designed as load-carriers. They therefore offer a higher degree of technical efficiency, avoiding the compromises involved in adding an attachment to an existing vehicle, and provide greater passenger comfort, more efficient braking and transmission systems, etc. However they may also incur a cost penalty.

Motor cycle based vehicles can be used on unpaved rural tracks to a certain extent, especially in dry weather. However, vehicles based on motor scooter technology which have small diameter wheels are not suited to use on rough roads.

Transport capacity For passenger transport, these vehicles typically provide seating for 3-8 persons, depending on the size of the bodywork and the power output of the vehicle. The latter is a key factor in determining the payload for goods transport. The payload of a 150cc scooter based vehicle is typically about 500kg.

The sensible operating range of the vehicles is up to about 40km, and speed of travel is somewhat lower than a solo motor cycle, although in urban conditions they can maintain pace with the normal traffic flow.

Infrastructure requirements Vehicles based on motor scooter technology, with small-diameter wheels, are only suitable for use on paved roads. The small wheels, and consequent low ground clearance, render them unsuitable for use on rough or badly potholed roads and tracks. Larger-wheeled models are more suitable for rural use but the configuration of the vehicle makes it unsuitable for routes that consist of two parallel wheel tracks separated by a grassed central section.

Costs The purchase cost of the vehicles is typically 2-2.5 times that of a motor cycle of equivalent engine size, and is influenced by the type and complexity of bodywork fitted. As noted earlier, the vehicles are at present used primarily to provide passenger services. On fixed-route services, fares are somewhat higher than those offered by buses, and the main application is to operate on feeder routes. For flexible-route services, fares are typically 50 to 60 per cent of those charged by conventional taxis.

Manufacture For adaptations of motor cycles, metal fabrication, bodywork construction and well-equipped machining facilities are required. This type of vehicle is suitable for production by a medium-scale metalworking enterprise.

Local assembly of vehicles produced commercially overseas is feasible. However, local manufacture, with a local content that extends beyond bodywork construction and the use of locally produced ancillary components, is dependent upon there being sufficient demand to justify large-scale production.

5. Small diesel-engined three-wheeled vehicle

Applications These vehicles can carry goods, passengers or combined loads. At present they are used more in rural than in urban areas, although in technical terms they are suitable for both applications. Compared with petrol-engined three-wheeled vehicles they are usually slower and noisier, but more durable. The first two characteristics tend to make them less suitable for providing urban passenger transport services. However, the use of a diesel engine has the advantage, in rural areas, that it can be adapted to drive other devices, such as a water pump.

Transport capacity In India, vehicles operating on level ground with engines of 4.5kW carry loads of up to 1000kg, and vehicles with engines of 8.25kW carry loads of up to 2000kg.

Travel speeds are relatively low, with a typical cruising speed of 20-25km/h. However, some more recent and more sophisticated designs, intended for urban use, have a higher travel speed, but lower payload capacity.

Range of travel in rural areas is constrained by the low travel speeds.

Infrastructure requirements The vehicles can operate on rough rural tracks of sufficient width to allow the vehicle to pass, as long as relatively large-diameter wheels are fitted. Versions with rear wheel drive perform well in steep terrain.

Costs In comparison with a petrol-engined vehicle of similar specification, the purchase cost will be somewhat higher because diesel engines are expensive. However, use of a diesel engine results in lower running costs by reducing fuel and maintenance costs, and because of the longer life of the engine.

Manufacture Metal fabrication, bodywork construction and well-equipped machining facilities are required. This type of vehicle is suitable for production by a medium-scale metalworking enterprise.

6. Small diesel-engined four-wheeled vehicle

Applications Although these vehicles are occasionally found in urban areas, they are designed primarily for the movement in rural areas of goods, passengers or, most commonly, combined loads. This is the most expensive of the range of low-cost vehicles covered in this book but its major advantage is that its transport capacity is greater than the others. These vehicles may be purchased by more affluent farmers for their own use, though they will normally also be made available for hire, or they can be operated to provide rural transport services.

Transport capacity These vehicles typically have engines of between 6kW and 8.25kW with a corresponding payload capacity of 1,500-2,000kg. They are often used to carry passengers but are not normally fitted with bodywork specifically designed for transporting people.

Typical operating speeds are 30-50km/h, determined primarily by the power output of the engine and the gearing used.

Infrastructure requirements They are able to operate on rough or muddy rural roads and tracks of sufficient width to allow the vehicle to pass. They also perform well in steep terrain.

Costs A major determinant of purchase cost is the price that has to be paid for components taken from scrap motor vehicles. The indications are that purchase price will be about 50 per cent of that of a conventional light 1-tonne pick-up.

Operating costs are lower than for conventional light commercial vehicles.

Manufacture Metal fabrication, bodywork construction and well-equipped machining facilities are required. This type of vehicle is suitable for production by a medium-scale metal-working enterprise.

7. Single-axle tractor and trailer

Applications The essential justification for this vehicle is that it complements the use of single-axle tractors in agriculture. Its application is therefore for rural transport of goods (and accompanying passengers) in areas where single-axle tractors are an appropriate item of agricultural equipment. The most common pattern of ownership is by farmers who use the vehicle to meet their own transport requirements, and also make it available to others on a for-hire basis. The vehicle is not economically efficient unless the tractor is also used for agricultural activities and it does not therefore offer a sensible basis for providing regular transport services. Its crude control systems render it unsuitable for use in crowded urban streets.

Transport capacity Depending upon the power output of the tractor, which is typically between 4.5kW and 8.25kW, the trailer has a payload capacity of 750-1,500kg.

Travel speed is slow, typically 12-15km/h, determined by

the gear ratios available on the tractor. This slow speed of travel limits its effective range.

Infrastructure requirements The single-axle tractor and trailer can operate on rough or muddy tracks that are sufficiently wide to allow it to pass.

It can be used in steep terrain but payload is substantially reduced because of limitations on traction when traveling uphill, and on braking capacity downhill.

Costs The operating costs of a single-axle tractor and trailer, on a per tonne-km basis, are high. However, if calculated on a marginal cost basis, as an adjunct to use of the tractor in agriculture, it is an economically effective means of transport.

Manufacture The manufacture of a trailer is relatively simple, the essential requirements being basic metal fabrication, machining and bodywork construction skills and facilities. The trailer is suitable for production by small, but well-equipped, metal workshops.

2.3 VEHICLE LEGISLATION

There are two aspects of vehicle legislation that are relevant to the use and local manufacture of low-cost vehicles.

1. All countries have regulations concerning the registration, insurance and use of motor vehicles. Often this legislation is based on the types of vehicles commonly used in the country and may not take account of the requirements of new means of motorized transport that are introduced subsequently. Therefore, for public planners and decision-makers concerned with the selection, introduction and promotion of low-cost motorized vehicles, an important consideration is to ensure that existing legislation does not impose unnecessary or unintended constraints upon their effective use.

2. Equally, it is important for manufacturers of low-cost motorized vehicles to ensure that their products comply with the requirements of national regulations, for example in terms of overall dimensions, payload capacity, lighting and other safety-related systems.

MOTOR CYCLE ATTACHMENTS

3.1 INTRODUCTION

In the context of this publication the term 'motor cycle' refers to a motorized two-wheeled vehicle which also includes scooters. It is recognized that scooters have certain characteristics different from motor cycles and, where relevant, these are discussed.

The simplest types of low-cost motorized vehicle to produce are those which consist of attachments to standard motor cycles. Three types of motor cycle attachment, which can be fitted with little modification to the motor cycle, are considered here.

- two-wheeled trailer;
- sidecar;
- four-wheeled conversion.

The technical details of these three attachments are described in this chapter. However, it is necessary first to consider the selection of the motor cycle itself.

Selection of motor cycle

When manufacturing attachments for motor cycles, it is sensible to produce a limited range of standard products to fit selected models of motor cycle. This is much more efficient than producing the attachments on a 'one-off' basis to suit different models. It is therefore important to give some thought to the selection of the motor cycle models for which the attachments will be produced.

For trailers there is considerable flexibility since the key factor in determining whether a trailer will fit a motor cycle is the location of the hitch point. Section 3.2.1 discusses different hitch point locations to suit different types of motor cycle. However, it is also important to ensure that the payload capacity of the trailer is matched to the performance of the motor cycle that will tow it.

1. It is possible to tow a trailer behind a small motor cycle or moped of 50cc engine capacity. In this case a lightweight trailer with a recommended maximum payload of 100kg should be used.
2. In developing countries the common motor cycles are usually of 80-150cc capacity. For this size it is recommended that the maximum payload of the trailer should be about 250kg.
3. For larger motor cycles a heavy duty trailer with a greater payload can be used.

For the sidecar and four-wheeled conversion it is necessary to be more selective in the choice of machine because the geometry of the motor cycle frame and the location of the mounting points will determine the design of the chassis of the attachment. The following are the key considerations:

1. It is important to select a model, or a limited range of models, which are in common use and are easily available in the particular country.
2. The model(s) selected should have a good reputation for reliability, robustness and availability of spare parts.
3. The motor cycle should have an engine capacity of at least 80cc in order to have sufficient power to move a useful load at adequate speeds. In many developing countries the most popular motor cycles are of 80-125cc capacity, and it is these that are used successfully with sidecar and four-wheeled conversion attachments in the Philippines.
4. Motor cycles of 80-125cc engine size usually have one of two types of chassis construction - pressed steel, or welded tubular steel. It is preferable to use a motor cycle with a welded tubular steel chassis, since this will be stronger, and it is easier to fit additional brackets for the attachment.

It may be worth considering the use of the 'trail bike' type of motor cycle for the attachment of a sidecar if the vehicle is to be used on rough roads and tracks in rural areas. The trail bike is designed for off-road use, having high ground clearance, high traction tyres and low transmission ratios.

3.2 MOTOR CYCLE TRAILER

3.2.1 Overall configuration

An efficient, safe motor cycle trailer will have the following features:

- (i) an overall configuration which ensures that the trailer does not affect the normal handling of the motor cycle;
- (ii) a hitch mechanism which allows free rotational movement between the motor cycle and trailer, but prevents any free play in the joint which would cause snatching between the motor cycle and trailer;
- (iii) a simple and effective method of attaching and detaching the trailer.

The most common type of trailer has two wheels - one either side of a load-carrying container. The motor cycle acts as the third point of support, carrying part of the weight of the trailer and its payload. It is therefore important that the wheels of the trailer are positioned so that the centre of gravity of the load acts just in front of the axle line. This results in a small downward force acting on the motor cycle which contributes to the stability of the motor cycle/trailer combination.

Dimensions The size of the trailer will depend on a number of factors - cost, specification of towing motor cycle, loads to be carried, traffic regulations, density of traffic in the expected area of use, road conditions, etc. The size should suit the dimensions of any standard containers which may be carried in the trailer. These include oil drums,

tainers which may be carried in the trailer. These include oil drums, milk churns, packing cases, etc. For example, a 200 litre oil drum may be very useful for carrying kerosene or water.

A very large trailer will be unsafe in traffic and will encourage overloading, which can cause chassis failure and accidents. The trailer should not be too narrow either, as it will become unstable and liable to overturn. As a guide, Table 3.1 shows what are considered to be maximum overall dimensions for a two-wheeled motor cycle trailer.

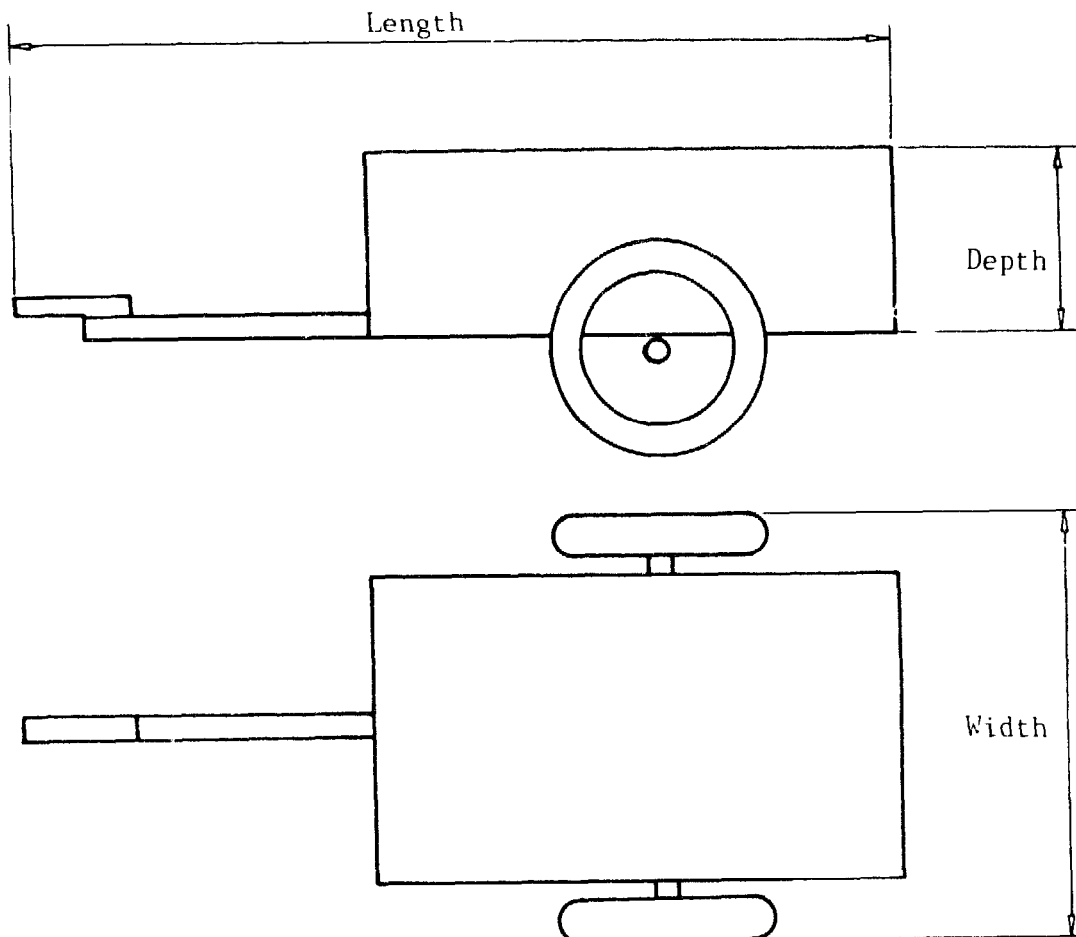


TABLE 3.1: Maximum overall dimensions of a motor cycle trailer.

Maximum payload (kg)	Maximum dimensions (mm)		
	Length	Width	Depth
150	1,200	850	300
200	1,300	900	350
300	1,600	975	410
400	1,850	1,050	450

The load carrying capacity of any vehicle is reduced when the terrain is hilly and the roads are of wet mud. A trailer that is to operate in these conditions should be smaller than one used mainly on level, paved roads.

The load-carrying capacity of any vehicle is reduced when the terrain is hilly and the roads are of wet mud. A trailer that is to operate in these conditions should be smaller than one used mainly on level, paved roads.

Point of attachment to motor cycle The hitch mechanism connects the trailer to the motor cycle and allows free rotational movement when cornering, going over rough ground, etc. Normally, one part of this mechanism is permanently attached to the motor cycle and the other to the trailer. The part which is attached to the motor cycle should be securely and rigidly fitted to the frame, and should not affect the operation of the rear suspension members.

Theoretically, the height of the coupling between the trailer and motor cycle should be below the motor cycle's rear axle line so that the momentum of the trailer when stopping presses down on the rear wheel, thereby increasing rear wheel braking force. A low coupling height also minimizes the extent to which vibrations of the trailer are transmitted to the motor cycle, thereby increasing stability. Because of the position of the rear suspension members, however, hitches have often to be located slightly above the axle height.

Mounting the hitch at seat height above the rear wheel is suited to small motor cycles equipped with a single seat, as Figure 3.1(a) shows. This configuration enables the total length of the combined motor cycle and trailer to be kept to a minimum and requires a relatively simple hitch mounting bracket. However, because of the decreased stability of this configuration, this mounting position should only be used on light-duty, low-speed motor cycle trailers. Figure 3.1(b) shows a motor cycle with a single seat and with the hitch mounted to the rear carrier. The carrier should be rigidly attached to the motor cycle chassis.

To mount the hitch at, or just above, axle height a hitch-mounting bracket will be needed. The preferred mounting areas of the bracket are shown in Figure 3.2. They are the region immediately adjacent to the top rear damper mounting, and the lower part of the main rear chassis member.

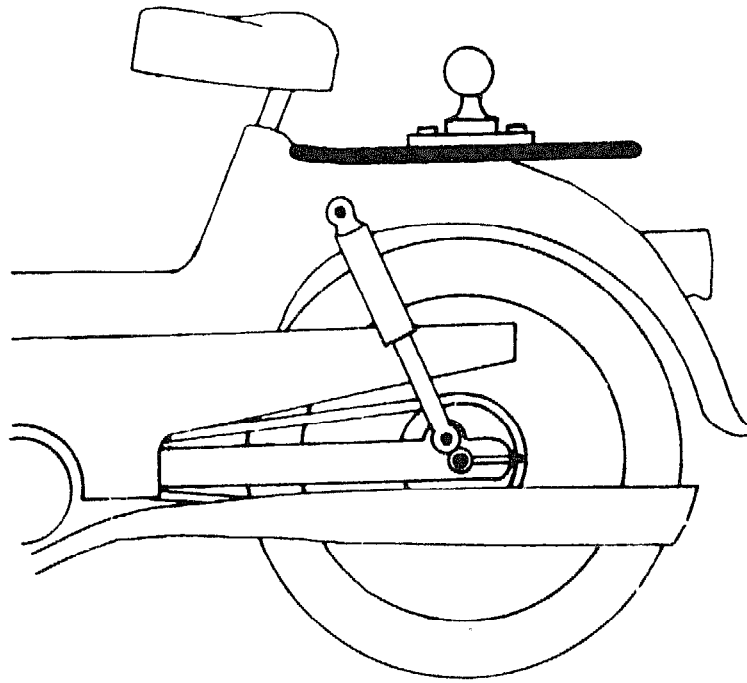
A different hitch-mounting configuration is sometimes used on scooters. The scooter frame design allows the hitch to be mounted mid-way between the wheels, underneath the rider (Figure 3.3).

A mud flap fitted behind the motor cycle rear wheel is an advisable addition. It will greatly reduce the mud splashed on to the hitch and the front of the trailer.

3.2.2 Chassis and suspension system

The following chassis designs are just a few examples of a large number of possible configurations. Annex 1 also discusses chassis construction.

T-frame This is the simplest type of frame used for motor cycle trailers (Figure 3.4). It consists of a longitudinal member, forming the tow-bar, which is joined at a right angle to the centre of a transverse member which supports stub axles at each end. Most types of pneumatic-tyred wheels can be used on this kind of frame, according to the specification of the trailer. The stub axles can be individually spring mounted to give independent suspension. This type of frame is suited to all capacities and requirements of motor cycle trailers. The frame should ideally be fabricated from hollow section mild steel, although channel section steel can be used if desired. This frame forms a basic chassis to which lighter



a) Diagram of hitch mounting



b) An example from Zimbabwe

Fig. 3.1 Trailer hitch attached to motor cycle rear carrier behind rider's seat

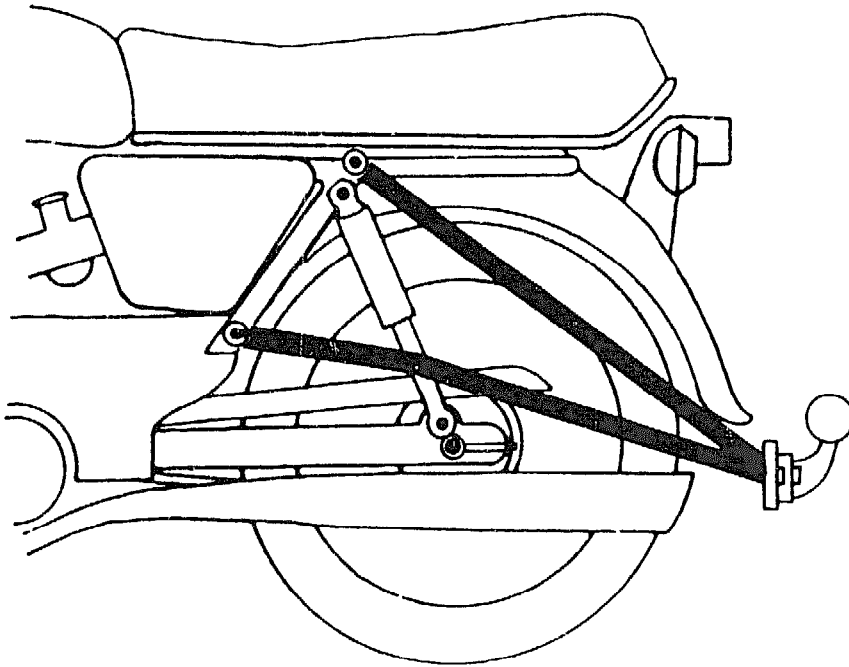


Fig. 3.2 Trailer hitch located behind rear wheel of motor cycle, and attached by means of a bracket

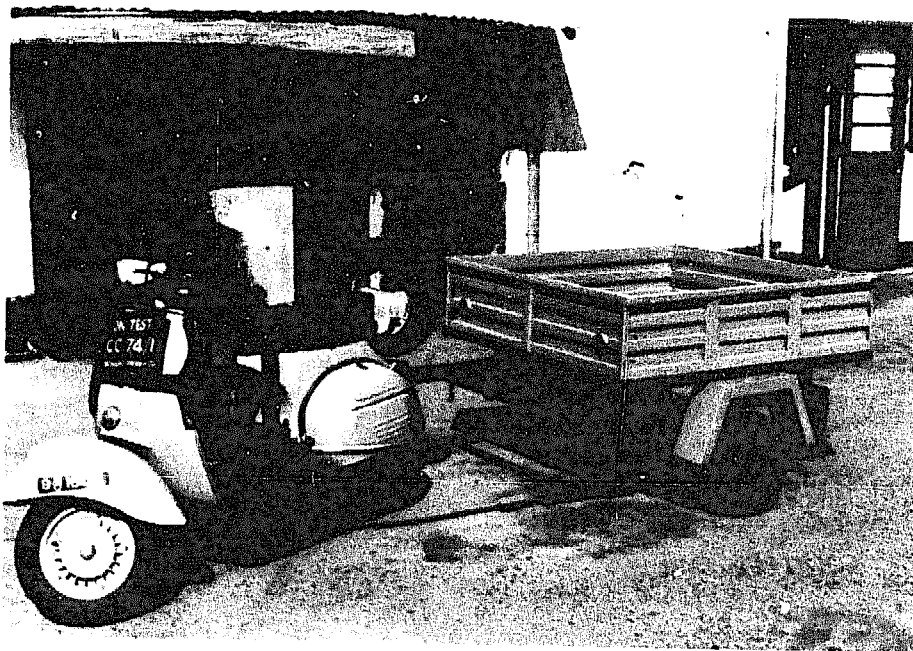


Fig. 3.3 Hitch location suitable for use with a motor scooter

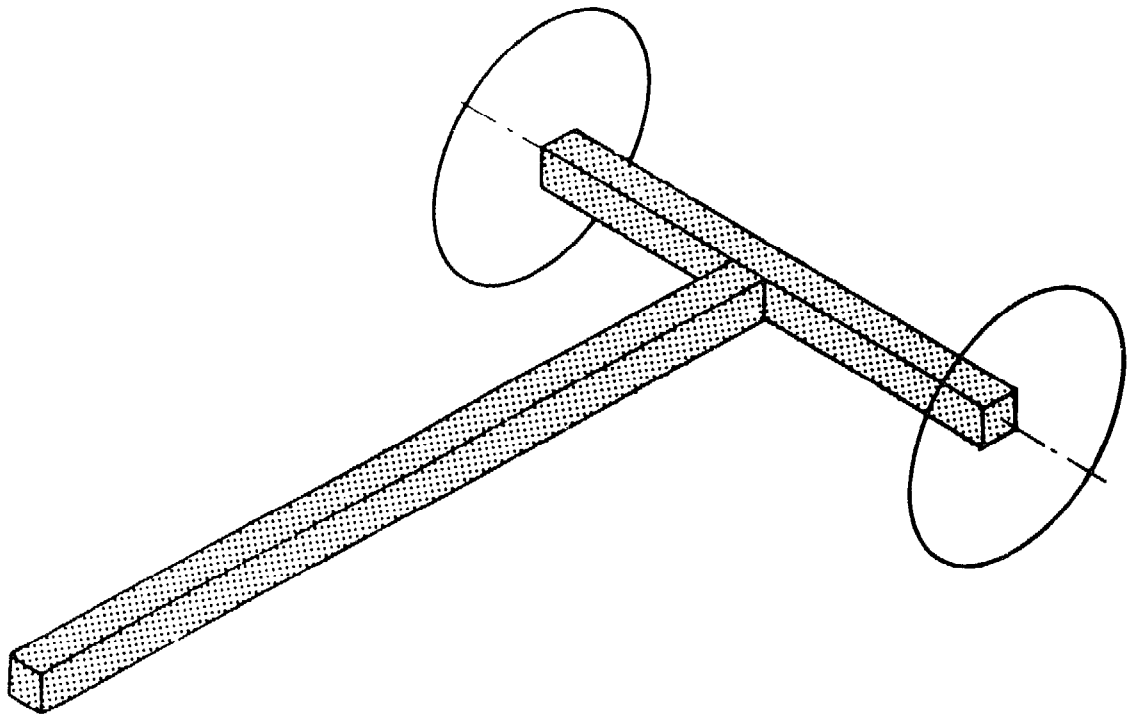


Fig. 3.4 Trailer T-frame

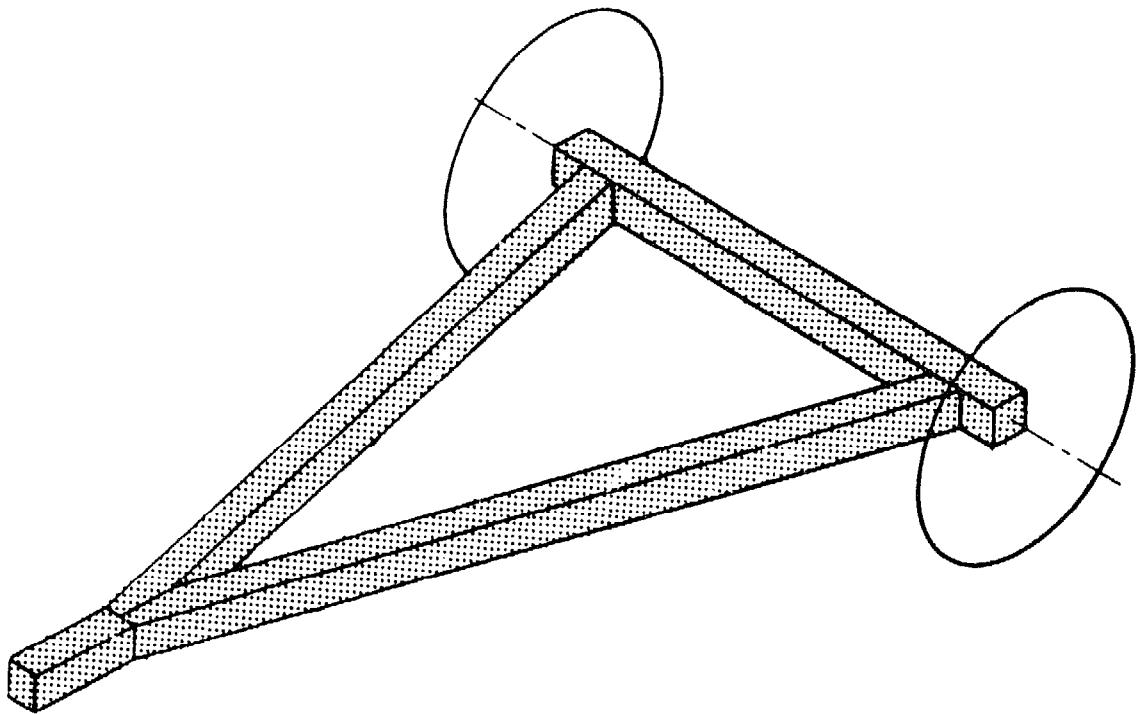


Fig. 3.5 Trailer A-frame

structural members may be added as required to form a load-carrying structure.

A-frame and ladder frame These frames are similar to the T-frame but, instead of a single longitudinal member, they have two - the A-frame members joining at an apex at the hitch point as shown in Figure 3.5, and the ladder frame having two parallel members with a short frame member forming the tow bar (Figure 3.6). The ladder frame gives all-round support to a rectangular load container and can be diagonally braced to improve its stiffness. The A-frame usually requires an additional rectangular frame to be mounted on to it to support a load container (see Figure A2.3 in Annex 2).

Sprung beam axle The sprung beam axle is described in Annex 3 and is mounted beneath the load-carrying unit. The beam axle itself is best fabricated from hollow section mild steel. The load-carrying unit forms the frame of the trailer and supports the tow-bar (Figure 3.7). A beam axle configuration is best suited to a heavy-duty motor cycle trailer.

Platform frame This type is best suited to light loads (up to 100kg) (Figure 3.8). Transport of greater loads would require additional members to be added to the base of the frame. It is fabricated from mild steel tube of 32mm diameter, and is designed for use with motor cycle wheels which are supported on both sides of their hubs. The design shown has the hitch point situated above the rear wheel and this is only suitable for light-duty, low-speed motor cycle trailers.

This design can be used as a basis for constructing a more complex structure, as shown in Figure 3.9. This frame is quite rigid and, for some applications, can be used without a load container. The design shown has the tow bar as a single length of tube, bent to form a 'loop' at the front of the trailer. The outer wheel supports are reinforced by additional braces which join the base to the tow bar. This ensures that the wheels are well supported and prevents any distortion of the frame during use.

Suspension The suspension requirements of a motor cycle trailer are less critical than those of vehicles designed to carry passengers. Suspension does increase the stability of the motor cycle/trailer combination. However, a lightweight trailer, especially when unladen, is prone to overturning when negotiating a corner on uneven ground. The incorporation of suspension significantly reduces the risk of this occurring, as well as reducing the transmission of jolts to the motor cycle which can affect its stability. Other benefits of suspension systems are described in Annex 3.

Suspension systems suitable for a motor cycle trailer can be divided into two categories:

- independently sprung wheels using trailing arms;
- beam axle.

The rubber-sprung arm unit described in Annex 3 is, strictly speaking, a trailing arm and is one of the most common types of suspension used on trailers. The units are often attached at either end of the main transverse frame member. Figure 3.10 shows such a unit mounted to the underside of a lightweight trailer towed by the mopeds of the Swiss Post Office.

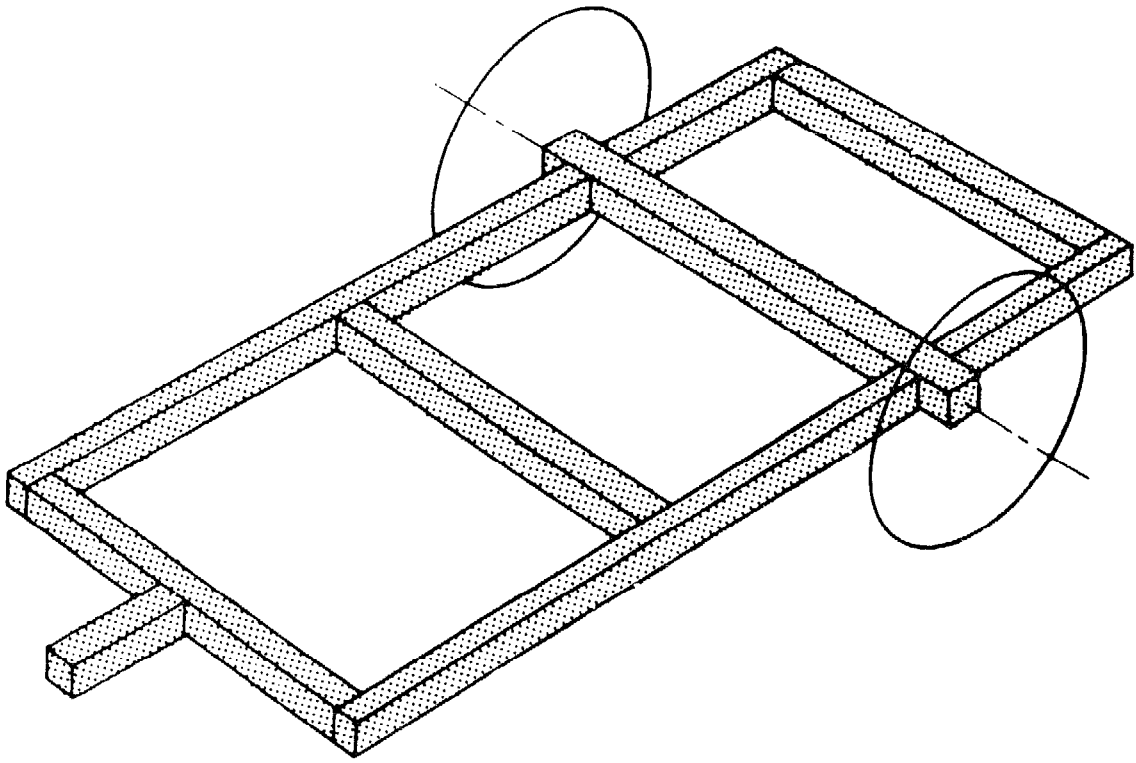


Fig. 3.6 Trailer ladder frame

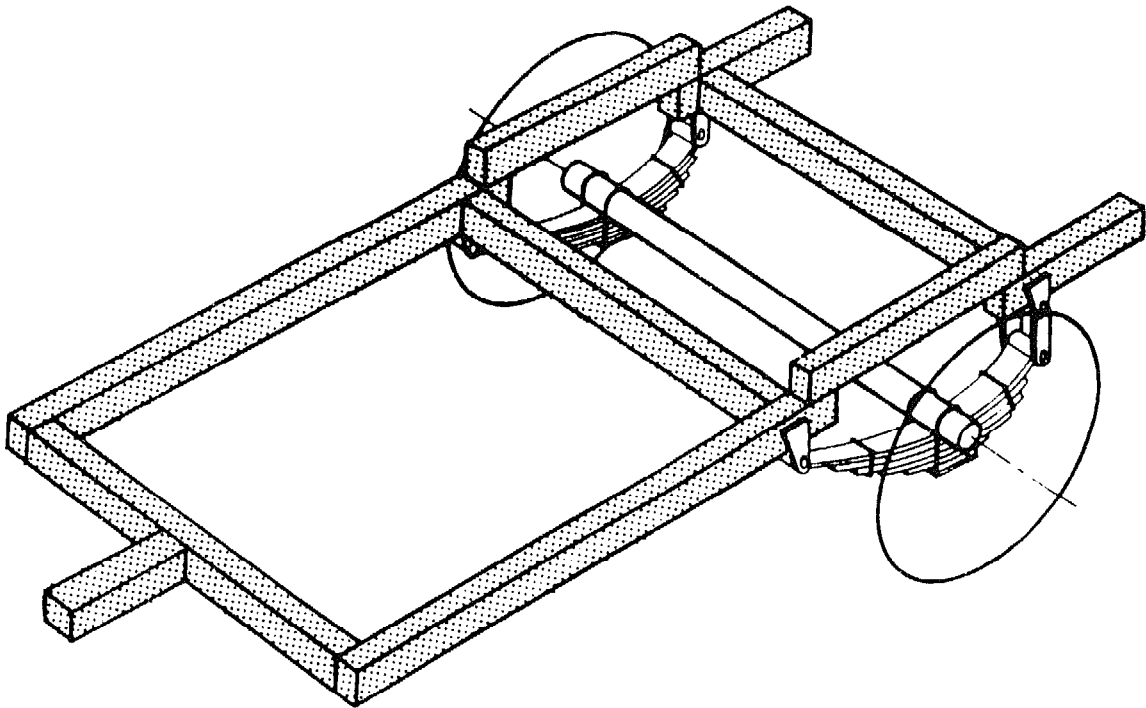


Fig. 3.7 Trailer chassis with sprung beam axle

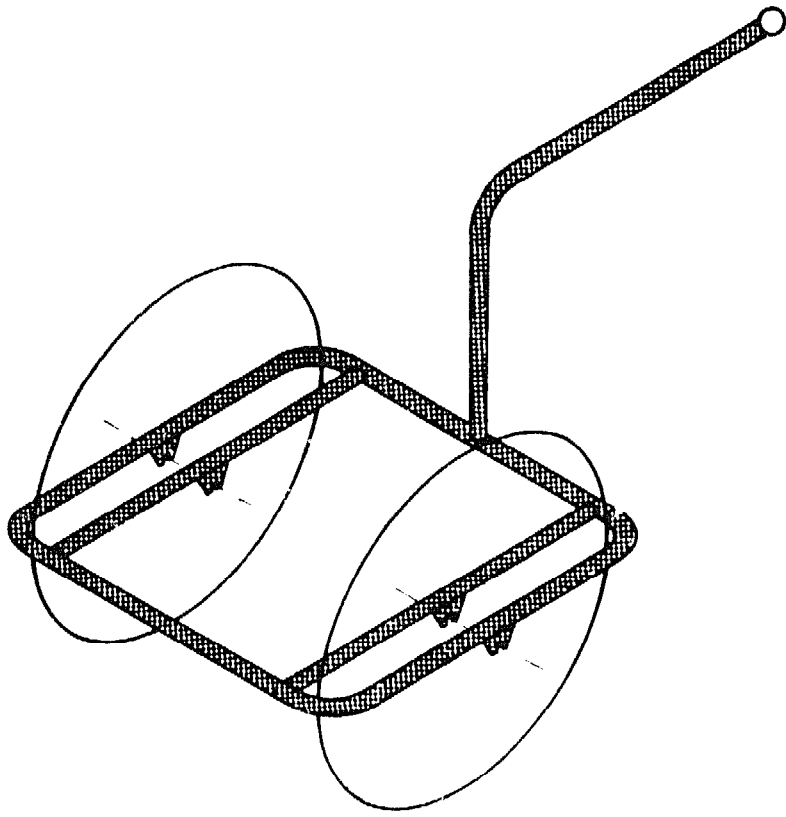


Fig. 3.8 Platform frame for lightweight trailer

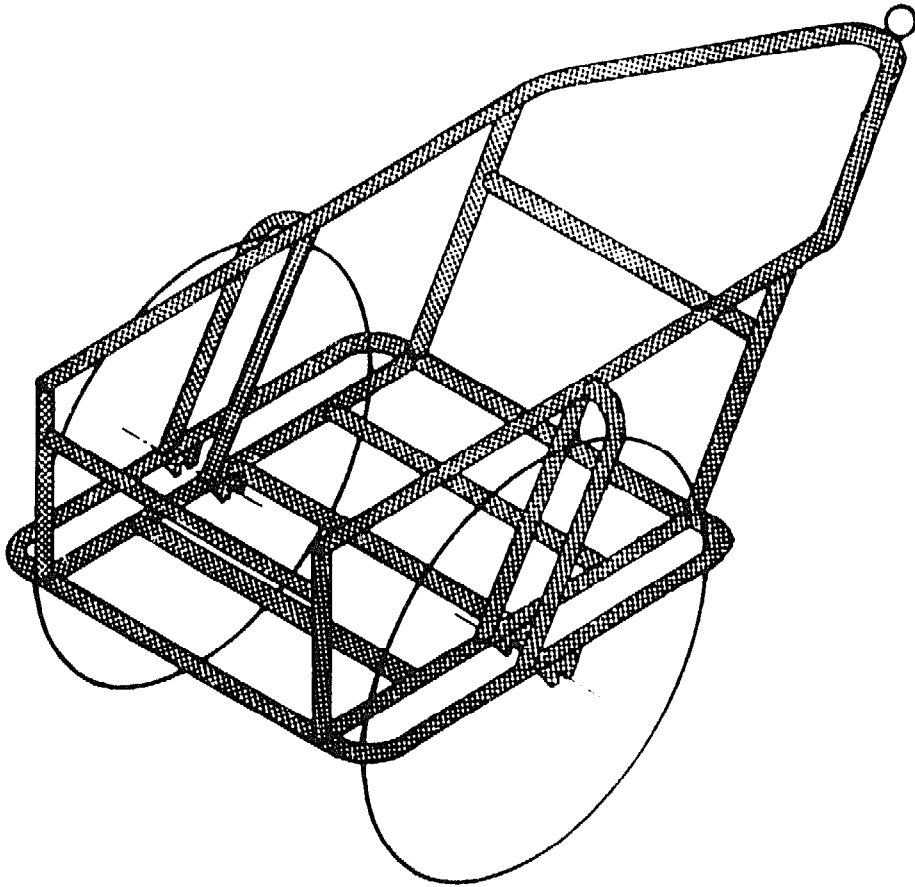


Fig. 3.9 Platform chassis with additional structural members to increase strength and rigidity of frame, and to provide framework for load container

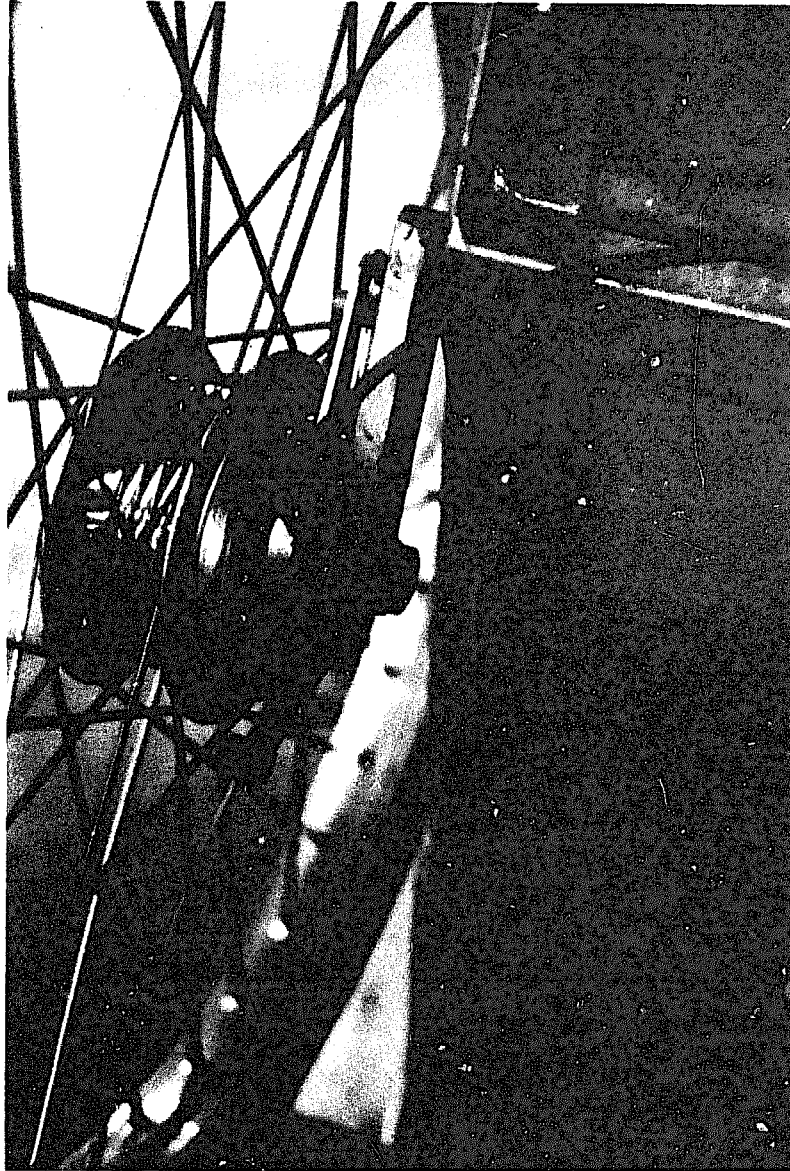


Fig. 3.10 Trailer fitted with rubber-sprung arm suspension and motor cycle wheels

Figure 3.7 shows a fabricated beam axle mounted on leaf springs.

If suspension is not used, the extent to which high-frequency vibration is transmitted to the load container can be reduced by using rubber mountings. This is discussed in Annex 3.

3.2.3 Wheels and hubs

Different types of wheels and hubs are described in Annex 5. The choice of wheels will depend on availability and requirements.

Small, scooter-type wheels are normally fitted to the commercially built trailers in developed countries. The use of these wheels facilitates a low load platform which, though very stable, will not be suitable for some uneven routes in developing countries because of poor ground clearance. If available, scooter wheels are best mounted on compatible scooter hub assemblies.

Motor cycle wheels are very suitable for a motor cycle trailer. Motor cycle wheels are used on the lightweight trailers towed by the 50cc mopeds of the Swiss Post Office (Figure 3.10). As described in Annex 5, this type of mounting is best accomplished with a modified hub. Fabricated wheels suitable for the fitting of motor cycle tyres can be made to suit the requirements of a motor cycle trailer (see Annex 5).

Motor car wheels are not ideal for lightweight trailers, but are suitable for heavy-duty versions. They are best used with compatible hub assemblies from a motor car.

3.2.4 Hitch mechanism

The hitch mechanism is, in many ways, the most important part of a motor cycle trailer. It connects the trailer to the motor cycle and allows free rotational movement in certain directions when cornering, going over rough ground, etc. However, it should not allow significant free play or slack which could create 'snatching' between the motor cycle and the trailer. Two-wheeled trailers require a hitch mechanism which allows rotation about three axes (Figure 3.11). Ideally, a swivel joint should be fitted to the hitch mechanism allowing full 360° rotation about the longitudinal axis. This facility ensures increased safety in the event of an accident.

The second function of the hitch mechanism is to allow the trailer to be attached to, or detached from, the motor cycle quickly, safely and easily. This function is central to the versatility and convenience of a motor cycle trailer, as it ensures that the owner can detach the trailer when it is not needed. Ideally, the method of attaching/detaching should not require any tools and should not involve removing any parts of the hitch for any length of time, as these may be mislaid.

As noted earlier, the hitch can be located above or behind the rear motor cycle wheel. In the latter case it must be attached to the motor cycle by means of a bracket. This typically consists of two forked members which are attached to the rear of the motor cycle chassis. The bracket is best fabricated from steel tube of at least 25mm diameter. Angle-section steel can also be used in this application but should not have sectional dimensions less than 40mm x 5mm. The bracket should only be attached at points on the chassis which are sturdy enough to resist the load imposed by the towing of a fully-loaded trailer.

The brackets themselves should be attached to the motor cycle chassis by bolts so that they can be readily detached. This will often necessitate the welding of lugs to the motor cycle chassis.

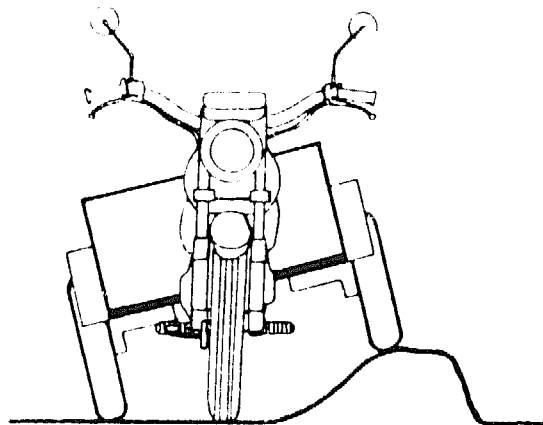
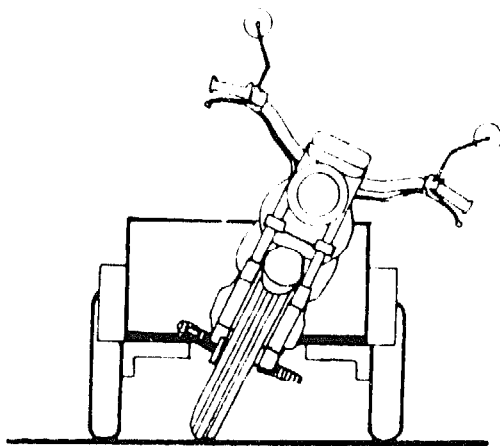
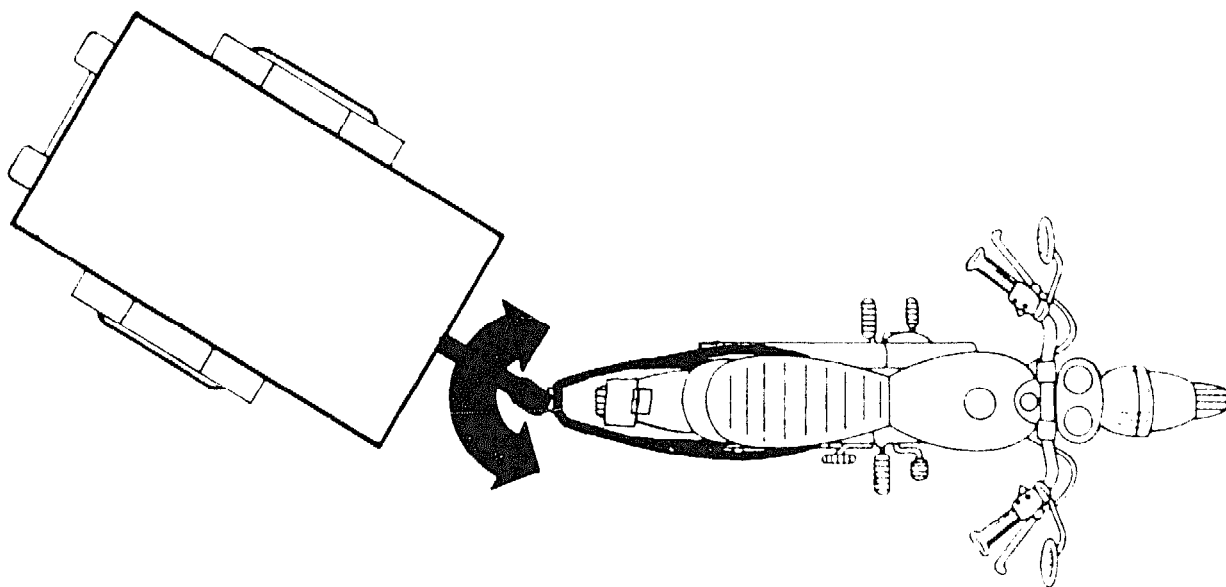
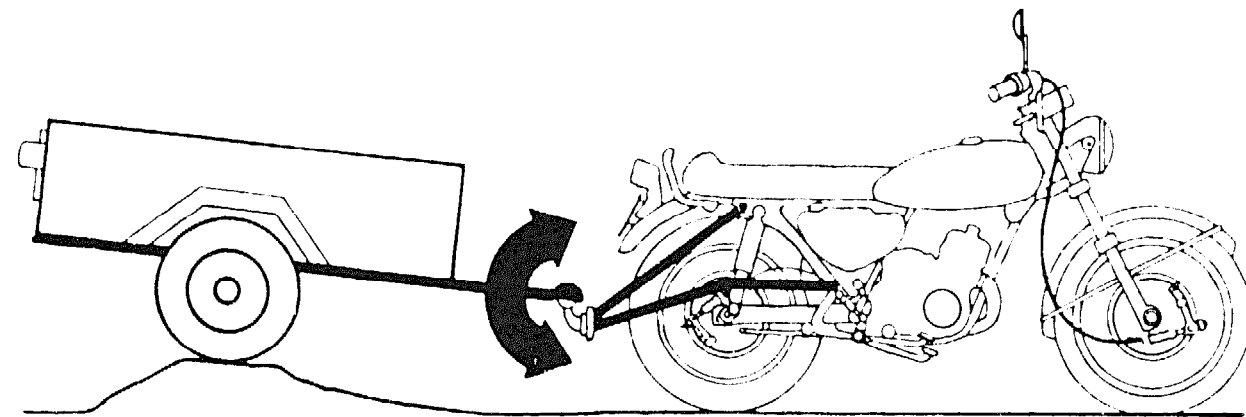


Fig. 3.11 Diagram showing relative movements between motor cycle and trailer to be provided for by hitch mechanism

The following types of hitch mechanisms can be used:

1. Standard commercial hitch

A standard hitch design has been internationally used for many years on a wide variety of vehicles and trailers. It consists of a 50mm diameter ball, usually made of forged steel, which is bolted to the rear of the towing vehicle. The trailer is connected to this by means of a housing, made of either cast iron or pressed steel, that combines a 50mm diameter socket, mounting holes to allow bolting to the trailer's tow bar and a handle to ease the operation of connecting and disconnecting the trailer. The coupling features a spring-loaded mechanism for locking on to the ball. An example of this type of coupling is shown in Figure 3.12. Hitches of this type are often used for towing motor vehicle trailers. They are quite suitable for use with motor cycle trailers but may be expensive or difficult to obtain in certain countries. Chapter 8 lists some manufacturers of trailer couplings.

2. Ball and socket

This device is shown in Figure 3.13. The hitch is similar in principle to the standard commercial device, it provides completely free rotational movement and prevents any 'snatching' between the motor cycle and the trailer. The hitch ball is mounted to the trailer and is attached to the motor cycle by locating it in the socket. The ball is retained by a high tensile steel bolt and wingnut. This hitch is made from mild steel and can be produced in a small workshop having basic machining and welding facilities. The ball is formed on a lathe from a short length of steel bar of 40mm diameter.

3. 'Universal' joint

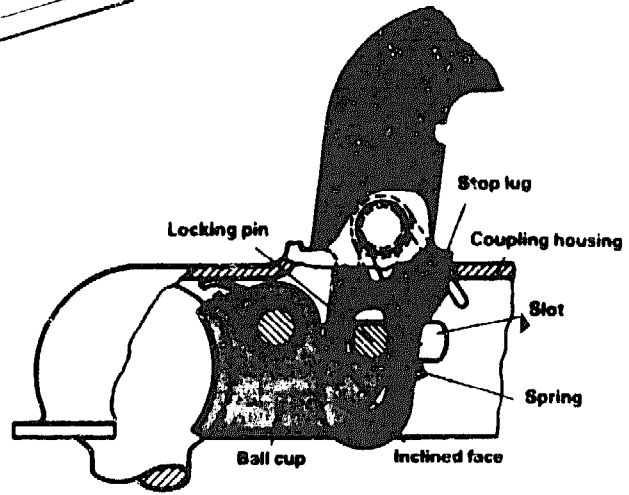
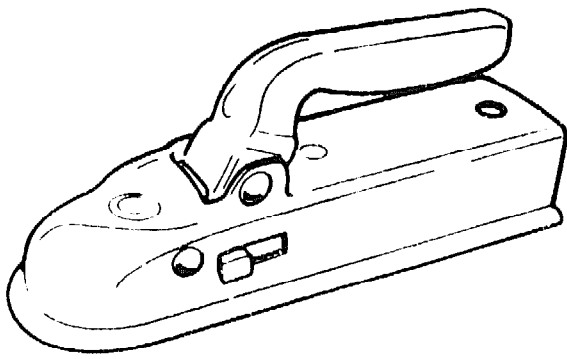
This design uses a 'universal' joint and a collar attached to the trailer frame to provide the required free rotational movement (Figure 3.14). The trailer is attached to the motor cycle by a T-shaped pin which passes through the hitch behind the collar on the trailer. The retaining pin should be at least 10mm in diameter, as it is subjected to considerable force during use. This hitch offers good performance and full 360° rotation. Its production requires fairly accurate machining.

4. Ball and clamp

The hitch shown in Figure 3.15 is used by the Swiss Post Office on its mopeds to tow lightweight trailers. The hitch is mounted to the moped frame above the rear mudguard. It consists of two jaws which are clamped together by means of a threaded hand wheel. The jaws grip a steel ball which is attached to the tow bar of the trailer. This type of hitch offers reasonable performance on a lightweight trailer and gives full 360° rotation. Considerable precision is required in its manufacture.

3.2.5 Bodywork

The bodywork of a motor cycle trailer consists of a load container and



Source: Indespension.

Fig. 3.12 Standard commercial hitch

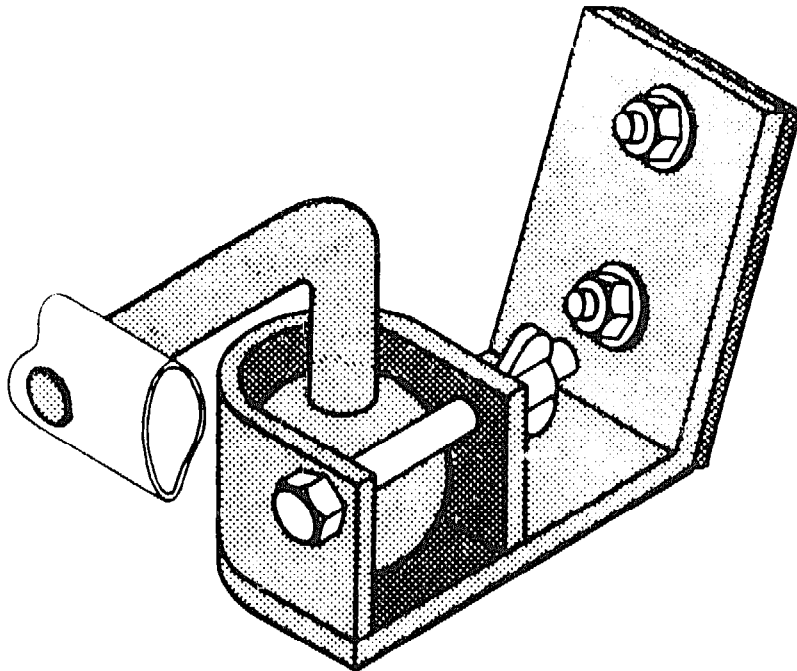


Fig. 3.13 Fabricated and machined ball and socket hitch

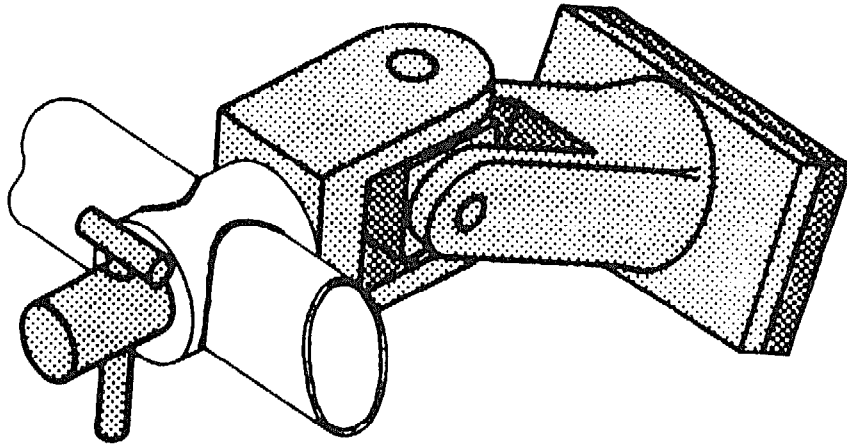


Fig. 3.14 Universal joint hitch



Fig. 3.15 Ball and clamp hitch

mudguards for the wheels. The poorly surfaced routes typically used in developing countries make the use of mudguards important when travelling at the speed of a motor cycle.

Different types of load containers suitable for use with a motor cycle trailer are described in Annex 2.

3.2.6 Brakes

Generally, motor cycle trailers do not require brakes and few commercial manufacturers fit them. Providing that the braking system and tyres of the motor cycle are in good condition, it is considered that a braking system would only be worth while on a motor cycle trailer with a gross load of 400kg or more. Automatic brake actuating mechanisms are sometimes fitted to large trailers towed by motor vehicles, but these are complex and tend to need regular maintenance.

3.2.7 Lighting system

Countries differ in their legal requirements for vehicle lighting. In many countries the mandatory lights required for a motor cycle trailer are: two rear lights including number plate illumination; two brake lights; rear-facing right hand and left hand turn indicators. Some countries may only require one rear light and brake light and no turn indicators.

The adaptation of the standard motor cycle lighting system to provide lights on the trailer is accomplished by 'tapping off' current from the wires connected to the individual rear lights of the motor cycle and directing it to the lighting system of the trailer. Various types of small electrical connecting devices can be used to effect the necessary joining of the wires. Sound electrical connections are vital, and it is especially important that there is no possibility of live wires becoming exposed.

A detachable electrical plug and socket assembly is used on most commercially produced trailers. This enables the trailer to be both quickly attached to, and removed from, the vehicle. In most countries, the favoured plug and socket assembly is the seven-pin type approved by the International Standards Organization (ISO). This assembly provides very reliable electrical connections and is shrouded to resist dirt and water. ISO-approved plugs and sockets are not available in all countries, however, and, in some cases, alternative wiring connections are therefore required. Care should be taken to wire the electrical connections so that they are subjected to minimal exposure to dust and water. The trailer lights should rely on a sound earth connection to the motor cycle chassis and **not** to the trailer frame. The film of grease on the trailer hitch inhibits its use as an electrical conductor. The individual wires should be bound together and attached to the trailer frame.

The addition of a trailer lighting system will cause an increase in the electrical current. This should pose no problems for the operation of the rear and brake lights, but may cause the turn indicators to flash more slowly. Many countries require the flashing rate to be between 120 and 60 pulses per minute. If the flashing rate becomes unacceptably low after wiring up the trailer indicators, then there are several options:

- (i) fit a flasher unit with a higher capacity;
- (ii) replace all indicator bulbs with ones of lower power rating;

(iii) dispense with indicators if local legislation permits.

Rear light units from motor cycles can be attached to the rear of the trailer. It is vital that the light bulbs are of the same voltage as that of the motor cycle's electrical system. The vehicle registration number must be displayed on a separate plate at the rear of the trailer and provision made for its illumination.

3.3 MOTOR CYCLE SIDECAR

3.3.1 Overall configuration

The sidecar attachment consists of a chassis fitted with a single wheel and its suspension system, which is rigidly mounted on to one side of the motor cycle:

- in countries where vehicles drive on the left-hand side of the road, the sidecar should be mounted on the left of the motor cycle;
- in countries where vehicles drive on the right-hand side of the road, the sidecar should be mounted on the right of the motor cycle.

The configuration of the chassis should be such that the axle of the sidecar wheel is on the same horizontal axis as the axle of the rear motor cycle wheel.

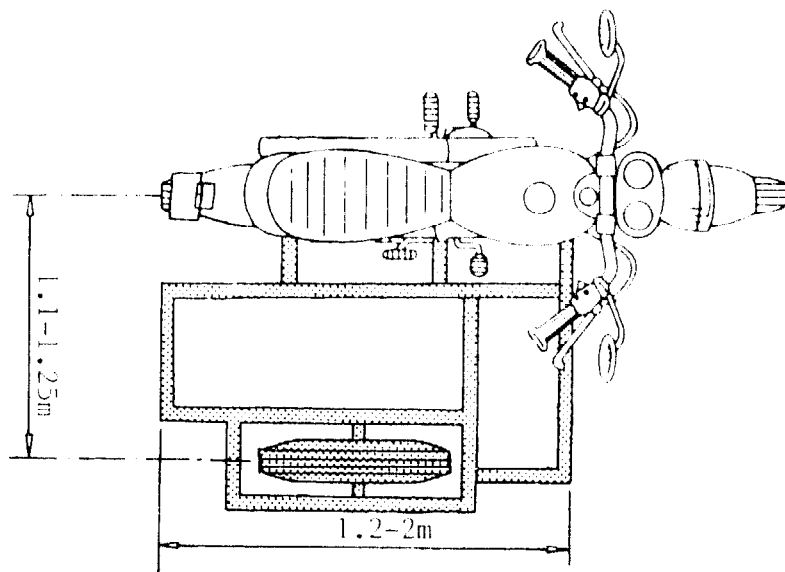
To ensure that the motor cycle and sidecar is stable, it is desirable that the centre of gravity of the loaded vehicle should be as low as possible, the main constraint being the need to maintain adequate ground clearance. The track (the distance between the motor cycle rear wheel and the sidecar wheel) will also influence stability. To achieve a satisfactory compromise between stability and manoeuvrability of the vehicle, the track should be 1.1-1.25m.

3.3.2 Chassis

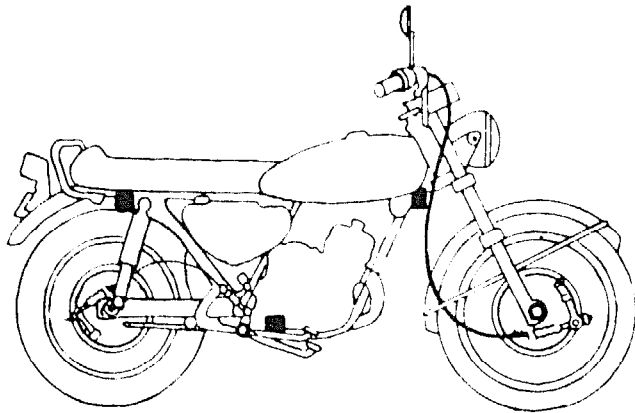
Attachment to motor cycle The attachment of the sidecar chassis to the motor cycle frame is critical to the satisfactory performance of the vehicle. The chassis should be rigidly attached to the motor cycle frame to form a single structural unit. It is preferable for the chassis to be attached to the motor cycle frame by bolted connections rather than welding, since this allows the sidecar to be detached easily if necessary.

The chassis should be attached to three points which should be well triangulated rather than in a straight line to minimize the stresses imposed on the mounting points. The ideal attachment points, as shown in Figure 3.16, are:

- (i) at the front of the motor cycle frame, immediately behind the steering head. This can be achieved by fitting a clamp around, or welding a mounting bracket to, the motor cycle frame;
- (ii) the rider's foot rest. This is best achieved using a clamp which is attached to the original foot rest. This allows the rider to use the foot rest as before;



a) Dimensions of sidecar chassis



b) Attachment points of sidecar chassis

Fig. 3.16 Schematic view showing attachment of sidecar chassis

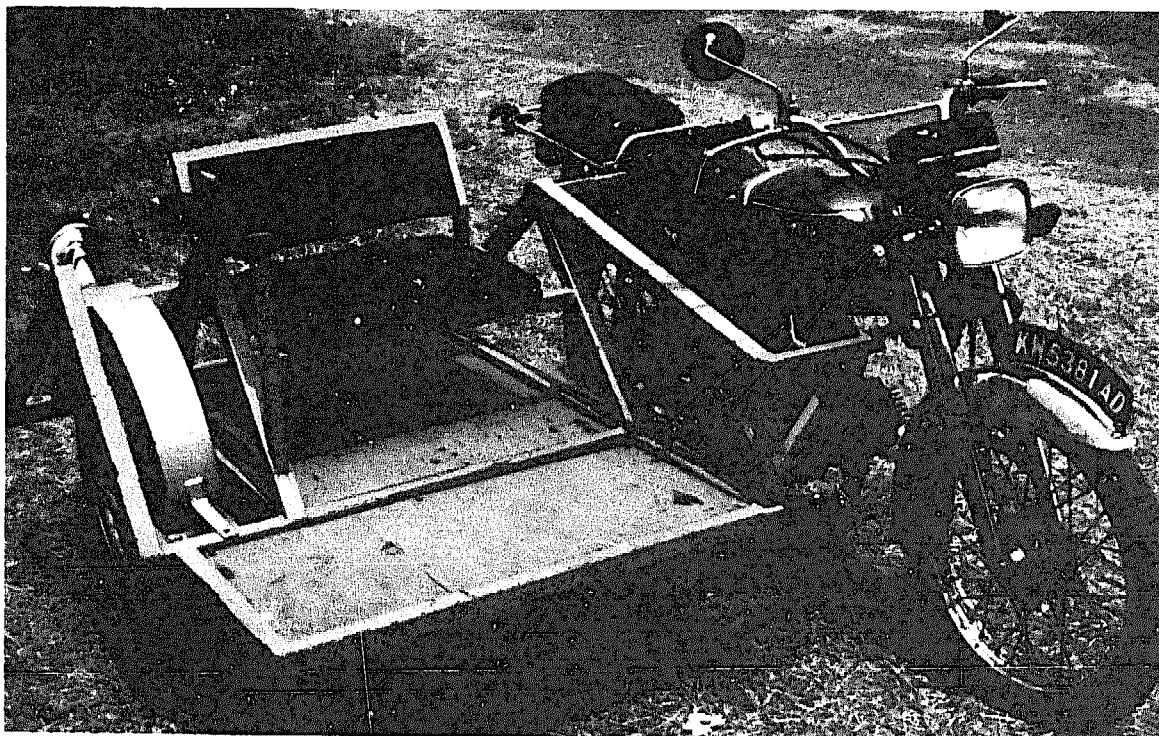


Fig. 3.17 Example of sidecar chassis constructed from square hollow section steel. (Note: the seat has been fitted temporarily for experimental purposes.)

(iii) the top rear coil spring/damper mounting. This is best achieved by welding a bracket on to the sidecar chassis which can be bolted directly to the existing mounting.

Configuration and construction of chassis. The sidecar chassis will consist of:

(i) three short lateral members projecting from the mounting points. These should be of sufficient length to provide adequate space for the rider's leg, and for his free movement to operate the foot controls;

(ii) a frame in the vertical plane to connect the three mounting points;

(iii) a horizontal platform to provide the base on which the body is constructed;

(iv) mounting for sidecar wheel and suspension.

The chassis in Figure 3.17 illustrates these elements clearly. However it should be noted that:

(i) the sidecar wheel mounting members on this design are more widely spaced than is necessary;

(ii) the seat design is experimental and is not very efficient.

Figure 3.18 illustrates the underside of another chassis and shows clearly the mounting of the trailing arm suspension unit.

The chassis should be of welded construction from steel hollow sections.

3.3.3 Suspension system

There are two basic options for the sidecar wheel suspension:

1. Trailing arm suspension, as shown in Figure 3.19. The arm is forked, running either side of the wheel, and pivoted in front of it. Normally two coil springs, or coil spring/damper units would be fitted, one on each side of the wheel. However, in the example shown an additional unit has been fitted to reinforce the sidecar suspension for use on rough roads. As an alternative to coil springs or spring/damper units, a leaf spring can be used. This would be of the quarter elliptic type with one end attached to the trailing arm at the wheel axle, the other to the chassis in front of the wheel.

2. Swinging arm suspension, (see Annex 3). The arm is pivoted underneath the chassis and supported on a semi-elliptic leaf spring. For this type of suspension a leaf spring is better than a coil spring/damper unit because it locates the arm fore and aft.

As an alternative to suspension the wheel can be attached directly to the chassis and a sprung load container used (Annex 3). However, except for urban applications on smooth roads, it is preferable to fit suspension.



Fig. 3.18 Underside of chassis of Filipino sidecar showing mounting for trailing arm suspension

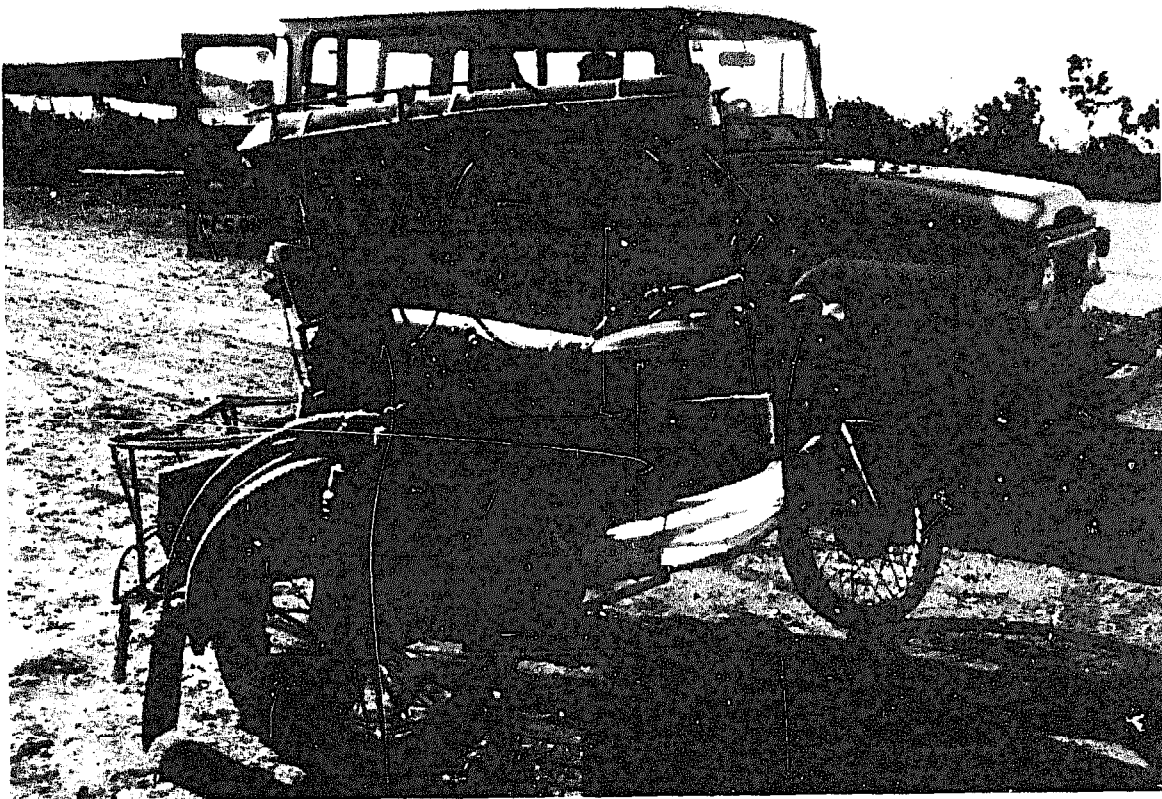


Fig. 3.19 Sidecar with trailing arm suspension. The suspension is fitted with two coil spring/damper units to withstand operation on rough tracks

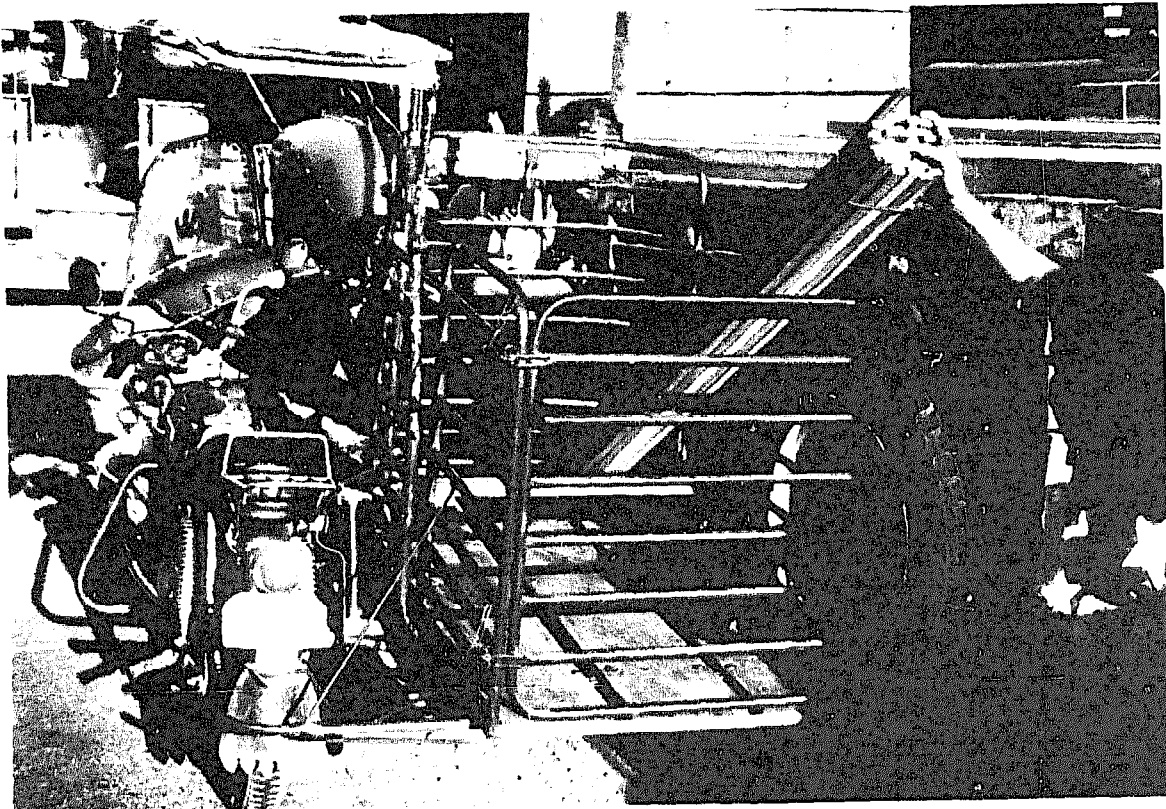


Fig. 3.20 Cargo-carrying sidecar

3.3.4 Wheel and hub

With trailing arm suspension, where the wheel is supported on both sides, a standard motor cycle wheel and hub can be fitted. With swing arm suspension, where the wheel is supported only on one side, either a motor cycle wheel with an adapted hub, or a fabricated wheel (both as described in Annex 5) can be fitted. If spoked motor cycle wheels are used it may be necessary to reinforce them to withstand heavy-duty use.

3.3.5 Bodywork

A variety of different types of passenger and cargo bodywork, as described in Annex 2, can be constructed on the chassis. Figure 3.20 illustrates a simple cargo body.

Figure 3.21 illustrates a body with two rows of seats which can carry four passengers in reasonable comfort.

Figure 3.22 shows a combined passenger and cargo body. Within the enclosed area is a seat for two passengers. Behind it is an open area (like a small pick-up body) for carrying goods.

Figures 3.21 and 3.22 show how weather protection for the passengers is provided by means of a canopy, side panels and perspex windows. In Figure 3.21 the canopy has been extended to provide protection for the driver as well. Normally, a lightweight, tubular structure is attached to the basic bodywork to mount the canopy, side panels, etc. However, if luggage is to be carried on the roof of the sidecar, a stronger structure must be used to be able to support the additional weight.

3.3.6 Brakes

It is not normal practice to fit additional braking on the motor cycle wheel.

3.3.7 Lighting system

Because, with sidecar fitted, the vehicle is much wider than the original motor cycle, it is important to fit an additional rear light and brake light on the sidecar. It is also desirable to fit an additional front light to show the width of the vehicle when operating at night. These additional lights can be wired into the existing motor cycle electrical system in the same manner as described for the trailer. However, unlike the trailer it is unnecessary to make provision for rapid disconnection of the additional lights and all the wiring can be permanently connected.

3.3.8 Reinforcement of motor cycle

For many urban sidecar applications, the motor cycle suspension system can remain unchanged. However, for heavy-duty use it may be necessary to stiffen the front suspension, as described in Annex 3.

For rural use on rough roads it is desirable to strengthen the rear suspension of the motor cycle. This is best achieved by fitting additional coil springs, or coil spring/damper units to the rear suspension. This is easily done by bolting adapter plates to the existing mountings to accept additional units.

For rural use it is also customary to reinforce the motor cycle wheels, particularly the rear wheel. This is done by fitting thicker spokes, and welding small diameter steel bars around the wheel rim.

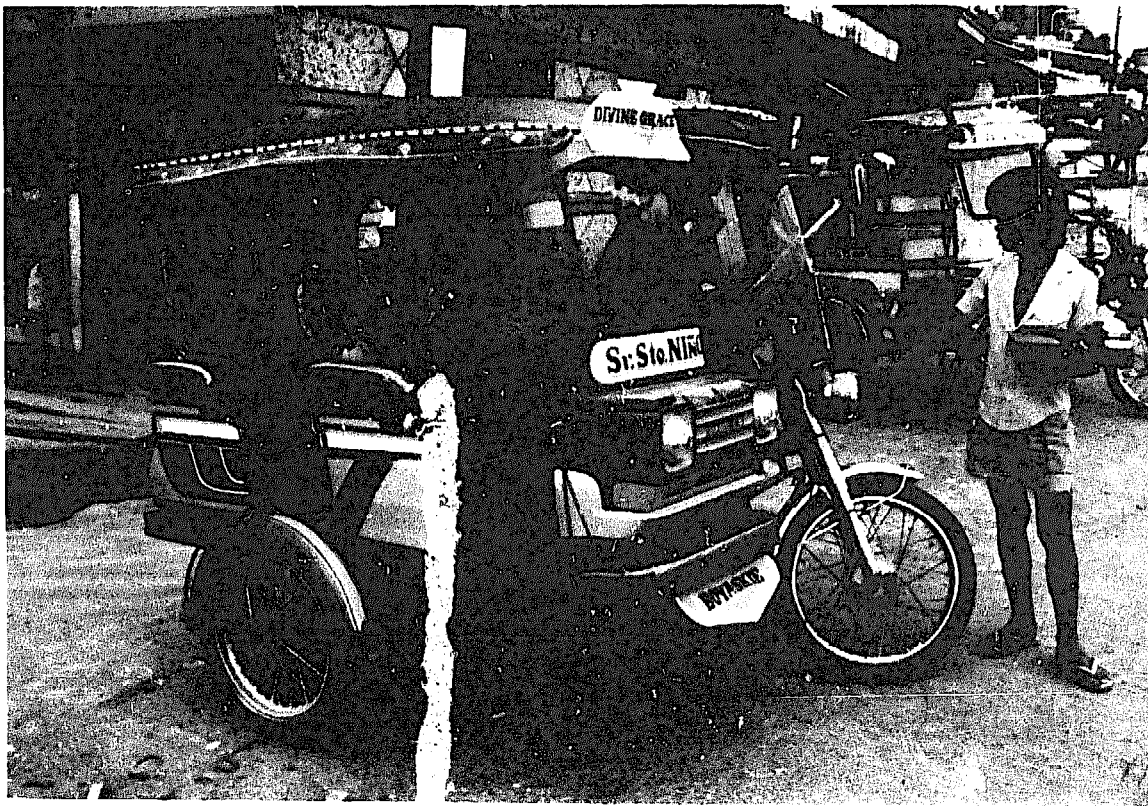


Fig. 3.21 Sidecar with seating for four passengers



Fig. 3.22 Sidecar with combined passenger and cargo body

3.4 FOUR-WHEELED CONVERSION OF MOTOR CYCLE

3.4.1 Overall configuration

This vehicle consists of a standard motor cycle to which is attached an additional chassis which passes around either side of the motor cycle and is fitted with a two-wheeled rear axle. Load-carrying bodywork is constructed on to this chassis. The chassis is attached to the motor cycle frame at:

- (i) the front of the frame immediately behind the steering head;
- (ii) the rear suspension.

Overall dimensions The additional wheels should not be positioned too far behind the rear motor cycle wheel or poor steering characteristics will result. The recommended distance from the centre line of the additional wheels to the motor cycle rear axle is about 0.5m (i.e. the wheelbase is increased by about 0.5m). The recommended distance between the additional rear wheels (the track) is about 1.5m. The axle line of the additional rear wheels should be positioned approximately mid-way along the length of the load container for good weight distribution.

Figure 3.23 shows the overall configuration of a typical four-wheeled conversion.

Exhaust pipe The exhaust pipe may need modifying because, in its standard position, the exhaust fumes can collect within the bodywork of the vehicle which is hazardous to the rider and any passengers who may be travelling in the vehicle. The exhaust silencer can easily be extended, and the fumes directed away from the vehicle, by the attachment of a steel tube of a suitable diameter.

3.4.2 Chassis

Figure 3.24 shows a typical chassis for this conversion, attached to the motor cycle frame.

Configuration and construction of chassis As shown in Figure 3.24, the conversion uses a flat platform chassis which completely surrounds the motor cycle frame. Welded to the chassis are the brackets for attachment to the motor cycle frame and for mounting the suspension which carries the two wheels. The chassis is best constructed from hollow steel sections of at least 50mm x 30mm x 3mm although channel sections of approximate dimensions 50mm x 25mm x 5mm may be substituted (see Annex 1).

Attachment to motor cycle frame The chassis is rigidly attached to the front of the motor cycle frame:

- (i) by clamps which fit around the tubular frame members; or
- (ii) by welding a bracket on to the motor cycle frame to which the chassis can be bolted.

The rear of the chassis is attached by links to the trailing arm that supports the motor cycle wheel, as shown in Figure 3.24. The links are pivoted at each end to allow the motor cycle wheel to move relative

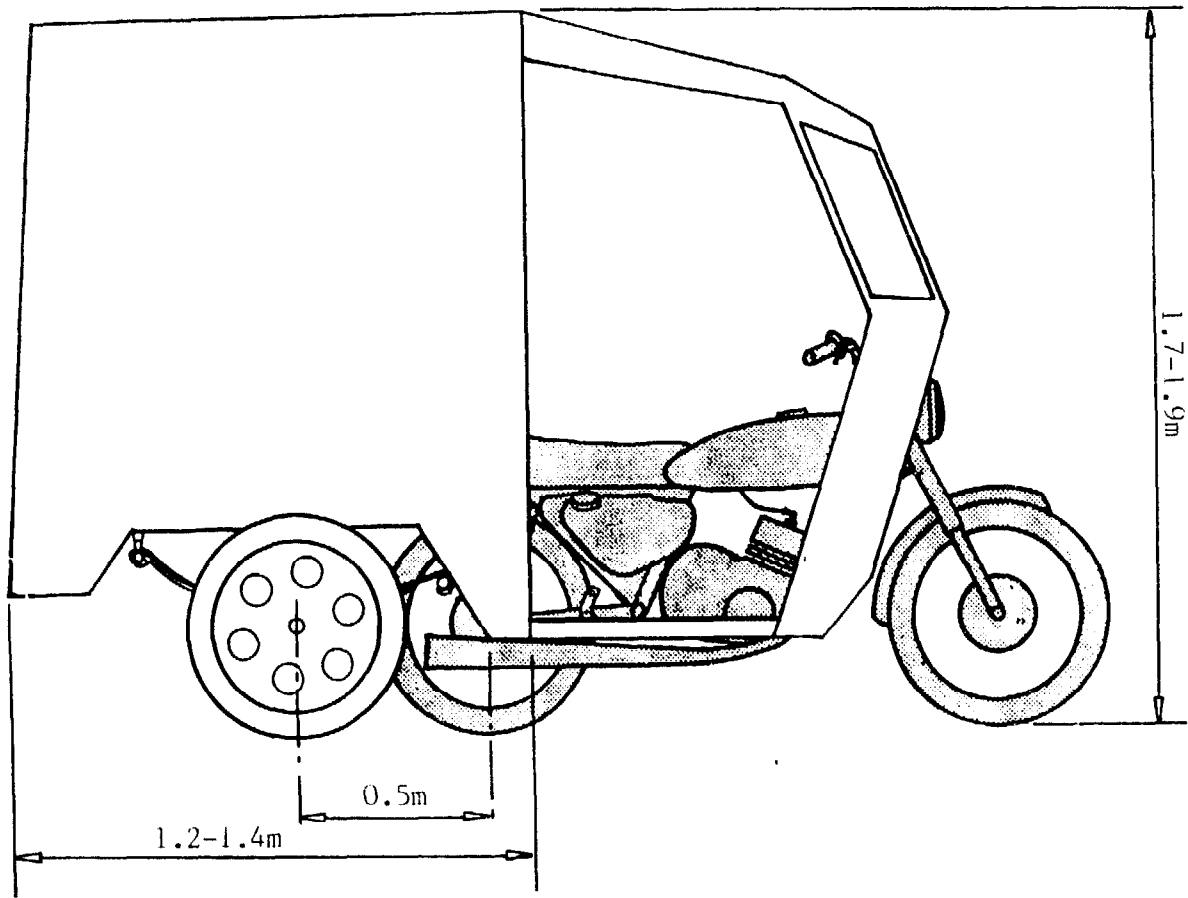


Fig. 3.23 Typical configuration of four-wheeled conversion of motor cycle

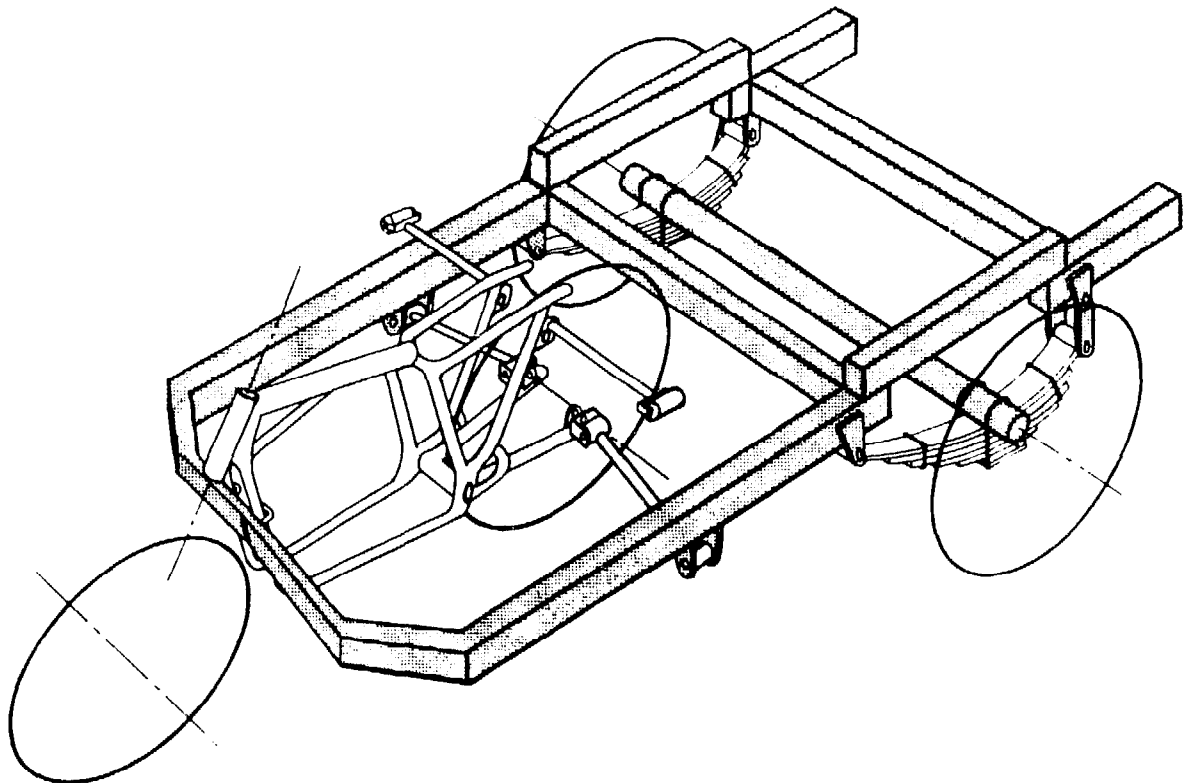


Fig. 3.24 Chassis for conversion showing method of attachment to motor cycle frame and rear suspension system

to the chassis as the motor cycle rear suspension operates. The fact that the links are pivoted also reduces the transfer of loads from the chassis to the trailing arm. The pivots should be mounted in rubber bushes to minimize wear, reduce vibration, and allow for slight mis- alignment of the links.

Two horizontal links, with rollers at their ends, are rigidly clamped to the motor cycle top rear spring/damper mountings (Figure 3.24). The rollers run on vertical rubbing strips which are located on the inner faces of the bodywork on either side of the motor cycle wheel. These rubbing strips should be attached to vertical extensions from the main chassis of the conversion. The rollers allow some relative vertical movement but prevent lateral movement between the conversion chassis and the motor cycle.

3.4.3 Suspension, wheels and brakes

The front and rear suspension of the motor cycle will normally remain unchanged. However, if necessary they, and the motor cycle wheels, can be reinforced in the same manner as described for the attachment of a side- car.

The most convenient suspension system for the conversion is to use a dead beam axle carrying a wheel at each end, suspended on semi-elliptic leaf springs. This system is illustrated in Figure 3.24 and described in more detail in Annex 3.

Standard motor cycle wheels can be adapted for attachment to the rear axle or alternatively a fabricated wheel that accepts a motor cycle tyre can be used (both methods are described in Annex 5).

It is not normal practice to fit additional brakes to the conversion, the vehicle relying on the braking capacity of the original motor cycle.

3.4.4 Bodywork

The bodywork is constructed on the basic platform chassis, with additional frame members to support the body. Either cargo- or passenger-carrying bodywork can be fitted and it is normal for the body to incorporate partially enclosed protection for the driver. Figure 3.25 illustrates a typical cargo-carrying body which has the following features:

- (i) weather protection is provided in front of and above the driver, but the sides are open for easy entry and exit;
- (ii) floorboards are fitted at the front of the body (this allows additional passenger seating to be fitted to the front of the load container on either side of the driver);
- (iii) construction is in aluminium and corrugated galvanized sheet;
- (iv) mudguards are fitted over the rear wheels.

Figure 2.3 illustrates typical passenger bodywork for this type of vehicle, fitted with two rows of bench seats. More detail of the seating arrangement is shown in Figure A2.1 of Annex 2.

Annex 2 provides further information on different types of passenger and cargo bodywork.

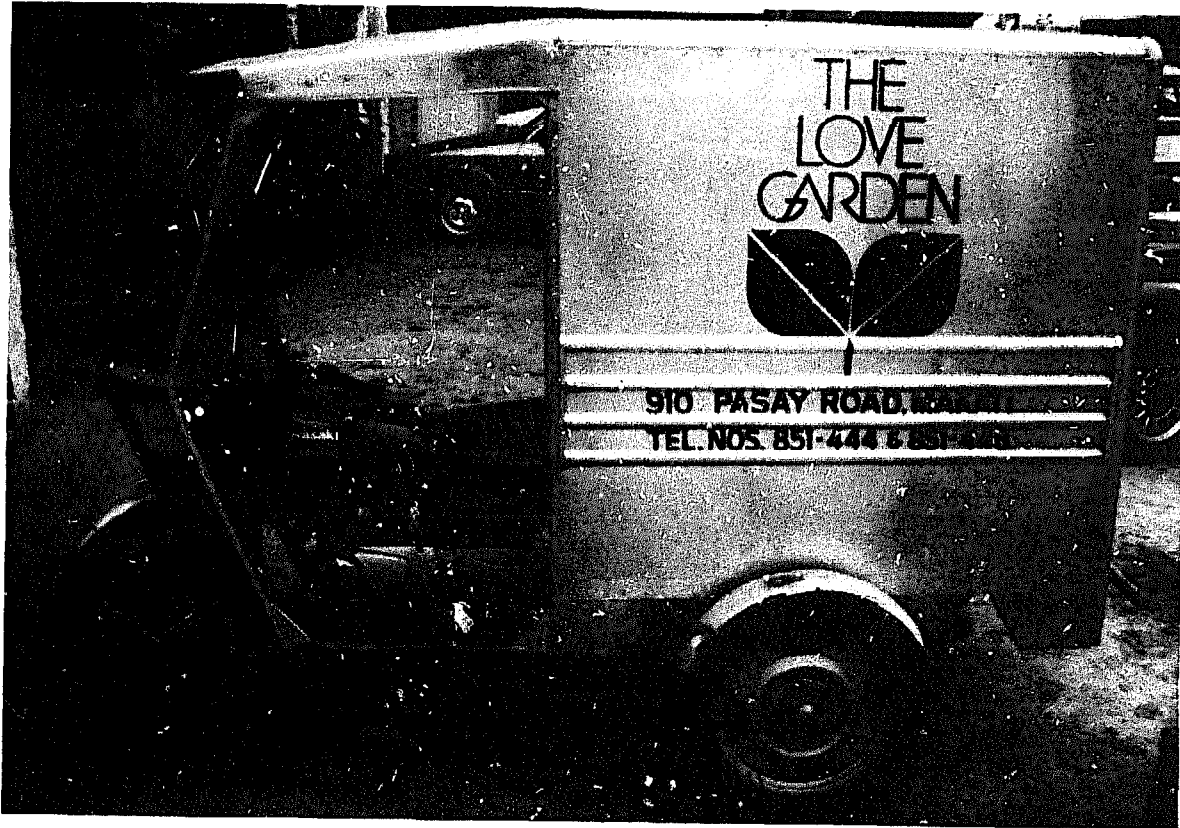


Fig. 3.25 Typical four-wheeled conversion of motor cycle with cargo body and weather protection for driver

3.4.5 Lighting system

Rear lights and brake lights can be attached to the conversion and wired into the motor cycle electrical system in a similar manner to that described in Section 3.2.7.

SMALL-ENGINEED THREE-WHEELED VEHICLES

4.1 INTRODUCTION

This chapter presents information on small-engined, load-carrying three-wheeled vehicles for the transport of goods and passengers. Compared with a four-wheeled vehicle of conventional configuration a three-wheeler has two significant disadvantages:

- (i) it is less stable, and it is therefore important to position the centre of gravity of the vehicle correctly (see Annex 4). However, a well-designed three-wheeled vehicle will have acceptable stability, particularly at the speeds at which they usually travel;
- (ii) because of its configuration it is difficult to operate on the type of rural track that consists of a pair of parallel wheel ruts separated by a grassed central section. Temporary wooden bridges that have two separate parallel wheel tracks are also difficult to negotiate.

However, the three-wheeled configuration also offers certain significant advantages over four-wheeled vehicles:

- (i) the chassis is simpler and lighter;
- (ii) for a vehicle with a single front wheel the steering arrangement is much simpler;
- (iii) the braking system is simpler;
- (iv) the number of components required is smaller.

As a result of these characteristics a three-wheeled vehicle will be cheaper to purchase, and have lower running costs, than an equivalent four-wheeled vehicle.

A variety of types of small-engined three-wheeled vehicle are produced in different parts of the world. Of this range two types are considered to be particularly suitable for small-scale manufacture in developing countries, and several commercially produced examples of the following are featured in Chapter 8:

- motor cycle based three-wheeled vehicle;
- small diesel-engined three-wheeled vehicle.

The first of these requires a brief definition. The previous chapter was concerned with devices which can be attached to an existing motor cycle, without modification or adaptation of that motor cycle, to increase its load-carrying capacity. Several motor cycle manufacturers also produce purpose-designed three-wheelers using the same basic technology as their two-wheelers.

There is also a third category of load-carrying vehicle based on motor cycle technology, which involves the modification or adaptation of a standard motor cycle to convert it into a three-wheeler. The adaptation

or conversion of motor cycles in this way is a very appropriate activity for small-scale industries.

4.2 THREE-WHEELED VEHICLES CONVERTED FROM MOTOR CYCLES

4.2.1 Selection of motor cycle

When establishing the manufacture of motor cycle based three-wheeled vehicles, it is sensible to concentrate on producing a conversion for just one, or for a limited range of, standard motor cycle models. This is preferable to attempting to produce conversions to suit any type of motor cycle which will result in high costs and make it difficult to introduce efficient production methods. The first consideration in the selection of the motor cycle for conversion is to choose a model, or a small range of models, which is in common use and is easily available in the particular country.

Within this constraint there are several other considerations in selecting a suitable model (or models) of motor cycle for conversion:

1. An important factor is the power output of the engine. While there are examples of 50cc mopeds being converted to load-carrying three-wheelers, these are only light-duty vehicles with limited carrying capacity. It is preferable to select a motor cycle with an engine capacity of at least 100cc. This will provide the power to propel a loaded three-wheeler at adequate speeds. In many developing countries the most popular motor cycles are of 80-125cc capacity and there are several examples of their successful conversion to three-wheeled load carriers. However, in some countries motor cycles of 175-250cc are also in common use and make a suitable base for conversion. Larger engined motor cycles, of greater than 250cc, are less common and are usually expensive (because they tend to attract higher rates of import duty and road tax, etc.). However, if a very heavy-duty vehicle is required, with a greater load-carrying capacity than can be provided using more easily available motor cycles, it is sensible to base it on a large-engined model.

2. The engine, transmission, brakes, etc., will inevitably be more highly stressed when the motor cycle is converted to a load-carrying three-wheeler. It is therefore important to select a model which has a good reputation for reliability and robustness. Motor cycle design is becoming increasingly sophisticated, and more models are becoming available with complex suspension, transmission and braking systems. However, it is preferable to choose a basic design of motor cycle with simple, well-proven systems to ensure reliability and ease of maintenance.

3. Motor cycles of 80-125cc engine size usually have one of two types of chassis construction - pressed steel, or welded tubular steel. It is preferable to use a motor cycle with a welded tubular steel chassis, since this will be stronger, and it is easier to fit additional mounting brackets for the attachment of the frame extension.

4. Scooters - motor cycles with small-diameter wheels and wide-section tyres - are an excellent basis for conversion to three-wheeled vehicles although they are only easily available in certain

developing countries. A scooter's small wheels are particularly resistant to the greater loads exerted by the cornering of a three-wheeled vehicle. A scooter also has a lower centre of gravity than a conventional motor cycle and this often results in a scooter-based three-wheeled vehicle being slightly more stable. However, because of the small wheels and low ground clearance, scooter-based three-wheelers are generally not suitable for rural use on rough roads and tracks.

4.2.2 Arrangement of conversion

There are two basic arrangements for a three-wheeled conversion of a motor cycle:

1. Two rear wheels/single front wheel: in this arrangement the load is carried behind the driver. The standard front end is retained, including the steering system, handlebar controls, rider seating and the engine and gearbox mounting. The rear end is converted to a two-wheeled arrangement and this involves adaptation of the transmission and rear braking system, and the fitting of a new rear suspension. An example of this arrangement is shown in Figure 4.1.

2. Single rear wheel/two front wheels: in this arrangement the load is carried in front of the driver between the two wheels. The standard rear end is retained including the transmission system and rear brake, the seat and the engine and gearbox mounting. The front end is converted to a two-wheeled arrangement and this involves the fitting of new steering, front suspension and braking systems, and the adaptation of the handlebar controls. An example of this arrangement is shown in example 4 in Chapter 8.

The second of these arrangements is restricted to light-duty applications since it is dynamically unstable except with light loads and at low speeds, and the available load-carrying space is limited. The preferred arrangement is therefore to have two rear wheels and a single front wheel. This option is more stable and safer, offers greater flexibility of use and allows heavier-duty applications. The following technical details concentrate on the first arrangement, conversions based on two rear wheels and a single front wheel.

4.2.3 Overall configuration of conversion

The following modifications are required to convert a standard motor cycle into a three-wheeled vehicle:

1. Disconnect rear braking and lighting system. Remove rear wheel, mudguard and suspension.
2. Fit chassis extension to motor cycle frame.
3. Fit suspension and rear wheels to chassis, and adapt transmission system to drive the rear wheels.
4. Fit braking system on rear wheels.

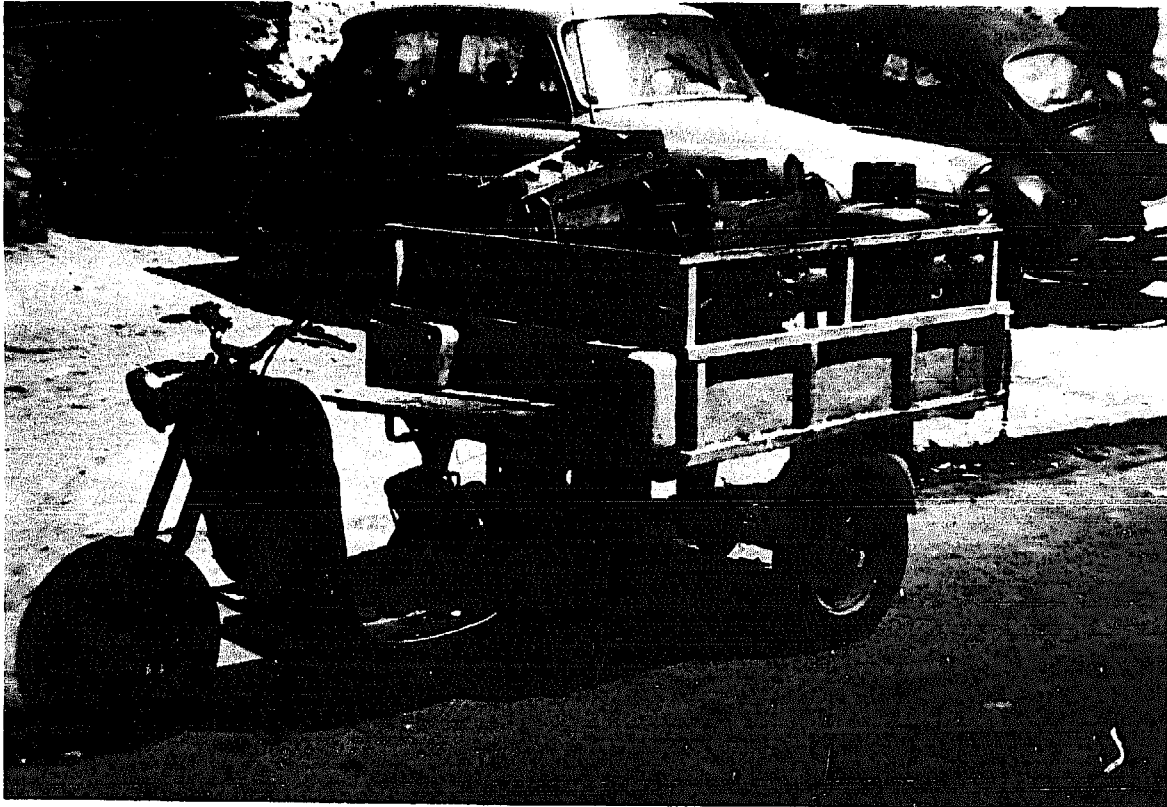


Fig. 4.1 Typical three-wheeled vehicle configuration with two rear wheels. Note also fuel tanks mounted on front of load container

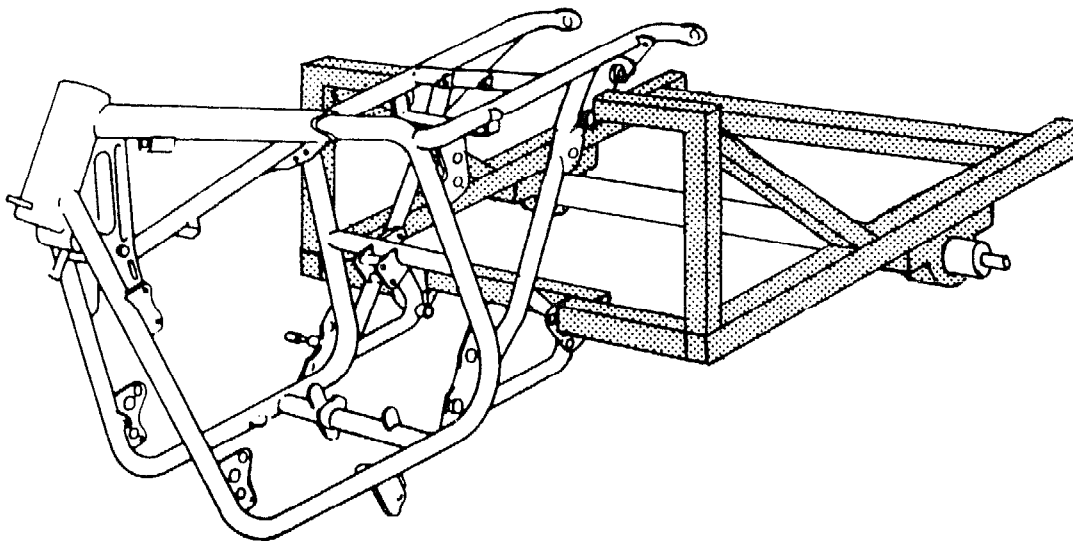


Fig. 4.2 Chassis extension bolted directly to motor cycle frame

5. Construct bodywork.
6. Add new rear lighting system.

All these modifications are discussed below, but there are certain other general considerations.

Overall dimensions The wheelbase (see Annex 4) of a three-wheeled conversion will normally be longer than that of the original motor cycle in order to provide an adequate load-carrying area. However, it is important not to make the wheelbase too long since this has certain adverse effects:

- (i) there is a risk of the chassis extension, and its attachment to the motor cycle frame, being overstressed;
- (ii) if the load space is too large, this increases the risk of the vehicle being overloaded beyond its design capacity;
- (iii) the adaptation of the transmission system becomes more complex;
- (iv) the manoeuvrability of the vehicle decreases.

It is recommended that the wheelbase should not be extended by more than one metre (1m). As a guide, the wheelbase of a three-wheeled conversion is likely to be between 1.75-2.5m, depending on the power of the motor cycle, and the conditions of operation.

The distance between the rear wheels of the vehicle is called the track (Annex 4). A wide spacing between the rear wheels of the vehicle will increase its stability and load-carrying area. If it is too wide, however, this causes adverse effects similar to those of extending the wheelbase. The track should never be wider than that of a small motor car or light (1 tonne) pick-up truck. In many situations there are advantages in making the track narrower than this. For example, it makes the vehicle more manoeuvrable in crowded city traffic. As a guideline the track of a three-wheeled conversion is likely to be between 0.9-1.25m.

Driver seating Most motor cycles suitable for conversion to a three-wheeled vehicle are equipped with a seat for two people. With this seat removed and a single seat for the rider substituted, the load-carrying area can be brought forward and the vehicle frame made more rigid. Motor cycle-based three-wheeled vehicles are sometimes fitted with a seat suitable for two people sitting abreast. Side rails can be added to both sides of this kind of seat for added safety.

Fuel tank On some motor cycle based conversions the fuel tank is relocated to allow the seat to be moved further forwards and so increase the load space at the rear. If taken too far, however, this modification can result in an uncomfortable riding position.

A scooter normally has the fuel tank situated above the engine and beneath the seat. This can be relocated to allow the load platform to be better positioned. On many scooter-based conversions one or two petrol tank(s) are mounted on the front of the load container (Figure 4.1).

Exhaust pipe The exhaust pipe may need modifying because, in its standard position, the exhaust fumes can collect within the bodywork of

the vehicle which is hazardous to the rider and passengers. The exhaust silencer can easily be extended, and the fumes directed away from the vehicle, by the attachment of a tube of a suitable diameter.

4.2.4 Chassis and suspension system

Chassis extension The chassis extension of the three-wheeled vehicle supports the rear suspension and final drive of the transmission system, the load platform and bodywork. The chassis extension must be securely attached to the motor cycle frame to form a single, structural unit for the vehicle. At least three mounting points are required to give adequate strength. The location of these mounting points will obviously vary with different types of motor cycle, but they should be spaced as far apart as possible, which will increase rigidity and reduce the stress on the frame members.

The attachment of the chassis extension to the motor cycle frame can be achieved by:

- direct welding;
- bolting to existing brackets on the motor cycle frame;
- welding additional brackets to the motor cycle frame and bolting the chassis extension to these.

Direct welding to the motor cycle frame will result in a very rigid structure, but has the possible disadvantage of eliminating the option of converting the motor cycle back to its original state. If the configuration of the motor cycle frame allows, the simplest method of attachment is to bolt the extension to existing brackets on the frame. On a conventional motor cycle frame suitable location brackets are the top coil spring/damper mountings, the passenger foot rest brackets and the trailing arm pivots. Figure 4.2 shows a chassis extension bolted to a motor cycle frame at the coil spring/damper mountings and the passenger foot rest brackets.

The simplest form of chassis extension is a rectangular load platform with additional members for the attachment to the motor cycle frame. The chassis should be fabricated from hollow steel sections as described in Annex 1. Figure 4.2 illustrates a chassis extension of this type. The centre of the load platform will usually be positioned just ahead of the rear axle line with the two rear wheels mounted on either side. The weight bias of the load in front of the axle should not exceed 60 per cent, however, to avoid the frame becoming over-stressed and the front wheel overloaded. As discussed in Annex 4, the weight distribution will have a major effect on the controllability of the vehicle and some experimentation with different load positions will be worth while. The load platform is usually positioned over the wheels when small-diameter scooter wheels are fitted, and between them when larger wheels are fitted, although the bodywork may then extend over the wheels.

Scooters sometimes have a large, central frame member. On a three-wheeled conversion this can be extended at the rear and bent up to support the underside of the load platform. The load platform is also secured to the upper members of the scooter frame to form a rigid structure.

If the three-wheeled vehicle is fitted with bodywork that extends forward of the rider, as in Figure 4.3, then additional mounting points will be required at the front of the motor cycle frame.

Front suspension The front suspension assembly of the vehicle can remain



Fig. 4.3 Motor cycle based vehicle with fully enclosing bodywork



Fig. 4.4 Converted motor cycle with motor car rear axle adapted to chain drive, and coil sprung load container

unchanged from that of the original motor cycle. However:

1. The front fork of the motor cycle may need stiffening to compensate for the increased vehicle weight. The method of stiffening is described in Annex 3.
2. As discussed in Annex 4, the steering geometry of a motor cycle is not ideal for a three-wheeled vehicle. If the rear of the motor cycle is attached to the chassis extension so that it is raised above its normal height, then the castor angle of the front forks will be increased which will improve the steering characteristics.
3. Leading link forks are sometimes substituted for the standard telescopic units, as described in Annex 3.

Rear suspension The rear suspension of a motor cycle based three-wheeled vehicle has to be designed in conjunction with the transmission system. Rear suspension design is therefore included in the discussion in the next section. However, in summary there are three options.

To avoid the complexities of providing suspension to driven rear wheels, it is common practice with this type of vehicle to attach the rear axle directly to the chassis extension and use a sprung load container. Figure 4.4 shows the chassis of an Indian three-wheeled vehicle based on a powerful 'Harley Davidson' motor cycle with a motor car rear axle and coil springs supporting the load container. This type of coil-sprung load container is best fitted with dampers to control its oscillation.

However, if facilities and resources allow, it is preferable to fit rear suspension to the vehicle. This can be done using a suspended live beam axle or, the most complex method, by independent suspension on each rear wheel.

Annex 3 gives more information on suspension systems.

4.2.5 Transmission system

The function of the transmission system is to transmit the drive from the motor cycle gearbox to one or both of the rear wheels. The complexity of the transmission can vary according to the level of performance required and the available resources. Many commercially produced three-wheeled vehicles use a drive shaft for transmitting power from the engine to the rear axle. However, for a motor cycle based conversion a chain drive configuration is more straightforward, cheaper and, because it is more elastic, gives smoother power delivery than a shaft drive (Figure 4.5).

It is possible to fit independent rear suspension to a motor cycle based conversion, with each rear wheel driven by its own chain drive, as described in Annex 3. However, this is a complex system and for most applications it is simpler to use a live beam axle at the rear. With a live beam axle the simplest transmission system is to extend the motor cycle drive chain to a sprocket on the rear axle. This will place some constraints on suspension movement and, if the wheelbase is very long, the chain may become too long for effective operation. In this situation the chain from the motor cycle can be arranged to drive an intermediate shaft which drives another chain to the rear wheels. It is preferable to avoid the need for this by limiting the length of the wheelbase, however.

Since the final drive chain must be extended beyond its original

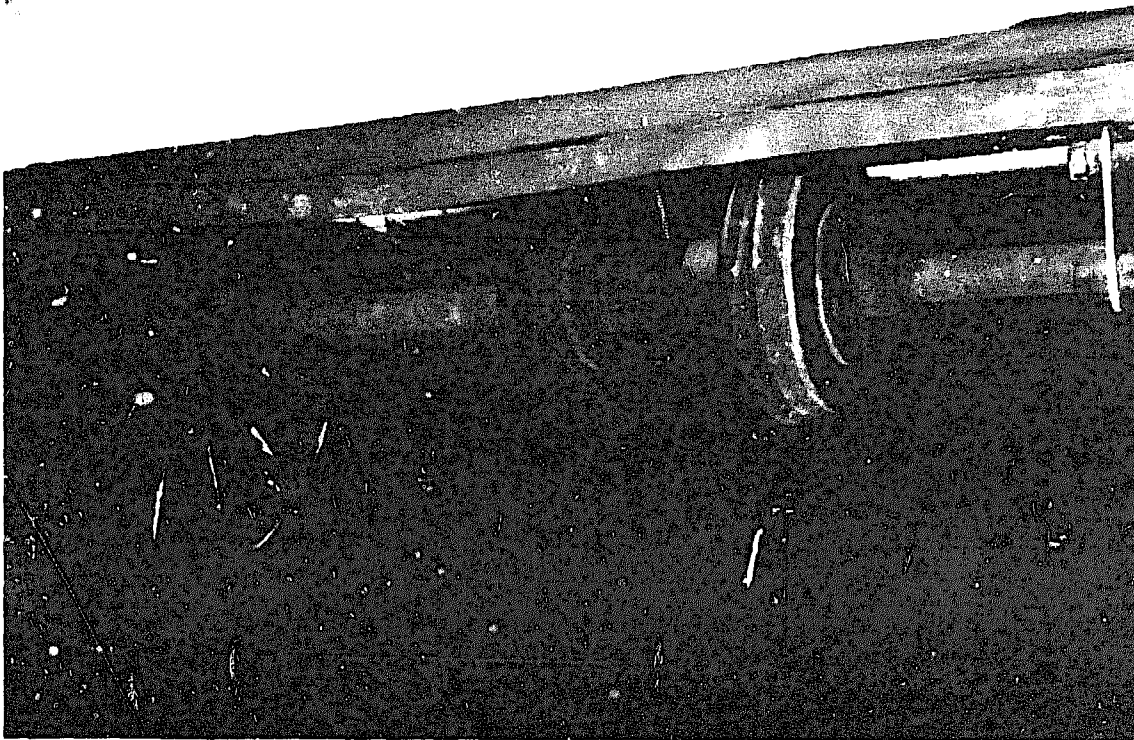


Fig. 4.5 Chain-driven live beam axle suspended on leaf springs and fitted with drum brake

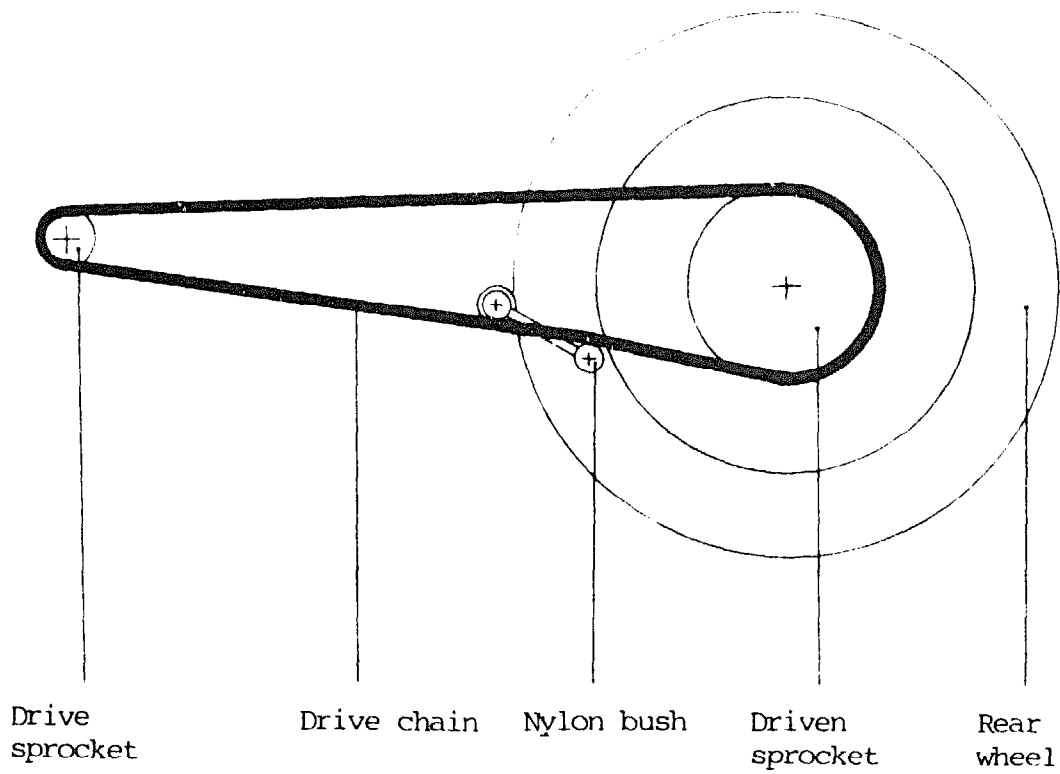


Fig. 4.6 Schematic diagram of chain tensioning device

length, this increases the likelihood of it becoming detached from the sprockets. For this reason it is important to maintain the chain at the correct tension. Some chain-driven three-wheeled vehicles rely on the removal of individual chain links to achieve the correct chain tension. However, it is preferable to fit a chain-tensioning device. These are usually spring-loaded small chain wheels or rubber slippers that support the bottom run of the chain and are usually positioned close to the final drive sprocket (Figure 4.6). By maintaining the chain in slight tension, these devices help prevent it from becoming detached and increase the smoothness of the power delivery.

A drive chain of the type used on the original motor cycle can be used on the converted vehicle, although it must be increased in length. The final drive sprocket on the rear axle can also be taken from a motor cycle. It is important to understand that the chain, along with all other transmission components, will be more highly stressed than on the original motor cycle.

The sizes of the motor cycle gearbox sprocket, the rear axle final drive sprocket and the outside diameter of the driven wheel(s) determine the final drive ratio of the vehicle. The final drive ratio of the converted vehicle will need to be lower than that of the motor cycle because the total vehicle weight when loaded will be substantially greater. It is determined by the following calculation:

$$\frac{T_1}{T_2} \times D$$

Where: T_1 is number of teeth on gearbox sprocket.
 T_2 is number of teeth on final drive sprocket.
 D is outside diameter of driven wheel(s).

Thus the final drive ratio can be reduced by:

- (i) using a larger final drive sprocket than that fitted to the rear motor cycle wheel (increasing T_2);
- (ii) using a smaller-diameter drive sprocket (decreasing T_1);
- (iii) using a smaller-diameter driven wheel than the rear motor cycle wheel;
- (iv) a combination of (i), (ii) and (iii).

Option (i) is the most preferable because it minimizes the load on the chain and sprockets.

As a guideline, the final drive ratio of the converted vehicle should be 20 to 40 per cent lower than that of the original motor cycle.

The simplest transmission arrangement is therefore to extend the motor cycle chain drive to a sprocket mounted on the live rear axle to which the two rear wheels are directly attached. The axle can be attached directly to the chassis, or via leaf springs. An arrangement of the latter type is shown in Figure 4.5. This type of rear axle is a single shaft which both transmits power and acts as a beam supporting the load platform. In order to fulfil both roles, this type of beam axle is typically a hollow steel shaft of substantially greater diameter than

that of a non-load supporting drive shaft. An example is shown in Figure 4.7. The axle-supporting bearings should be positioned as close to the wheels as possible in order to minimize the bending stresses imposed on the beam axle by the chassis. To accommodate any misalignment or deflections of the driven beam axle, it is desirable that it rotates in self-aligning bearings, which can be mounted in plummer blocks. These bearings are also better at resisting the axial loads experienced by the axle when the vehicle negotiates a corner than ordinary deep-groove bearings.

Use of differential unit When a three- or four-wheeled vehicle is driven round a curve, its outer wheel must travel a greater distance than the inner one and therefore complete a greater number of revolutions in the same time. Therefore, if both wheels are fixed to the drive axle, as described above, the vehicle can become difficult to steer, and tyre wear rate increases. It is therefore preferable to make provision on the drive axle to allow the wheels to rotate at different rates. On most commercially produced vehicles this is achieved by the use of a set of gears, usually mounted on the drive axle, called a differential unit. This device not only enables the drive wheels to revolve at different rates but also balances the driving torque equally between them.

A disadvantage with using a differential unit is that it drives two shafts, one for each wheel, each of which must be independently supported by bearings. This necessitates a relatively heavy, more complex construction for the rear axle. Rear axles incorporating small differential units for chain drive can only be locally produced by well-equipped workshops with gear-cutting facilities.

The rear axle assembly from a conventional motor car or pick-up can be successfully used in conjunction with a motor cycle to form a three-wheeled vehicle. The advantages of this arrangement are that it uses a strong axle with ready-made mountings for motor car hubs and wheels, and a differential that can be adapted to chain drive. The suspension mountings may also be useful for attaching the axle to the chassis.

A method is commonly employed in India to convert the differential unit from a motor car rear axle to chain drive. A sprocket is attached in place of the larger gear within the differential housing, and the rear of the housing is cut away to allow access for the drive chain. The rear axle is then fitted with the axial drive flange facing rearwards. This arrangement is used on the vehicle in Figure 4.4. Cutting holes in the rear of the housing, or removing it altogether, will result in the lubricant, normally present in the differential unit, leaking out. Regular lubrication of the internal gears is therefore necessary.

Because of the complexity and high cost of differential units and their associated rear axle assemblies, many low-cost, chain-driven vehicles feature an alternative method of enabling the wheels on the rear axle to rotate at different speeds. This is done by allowing one wheel to revolve freely relative to the axle, using a hub assembly, and the other to be fixed. An axle can be fabricated from a length of heavy-gauge steel tube, of around 50mm diameter, which is machined to accept bearings at each end (Figure 4.7 shows an example of such an axle). A final drive sprocket is bolted to a boss mounted on the axle so that it lines up precisely with the drive sprocket on the motor cycle. The disadvantage of this system is that only the fixed wheel transmits the driving torque to the road, resulting in inferior steering and traction characteristics compared to those achieved using a good differential unit.

When suspension is fitted to a rear beam axle there can be a large relative angular movement between the axle and the vehicle frame. This

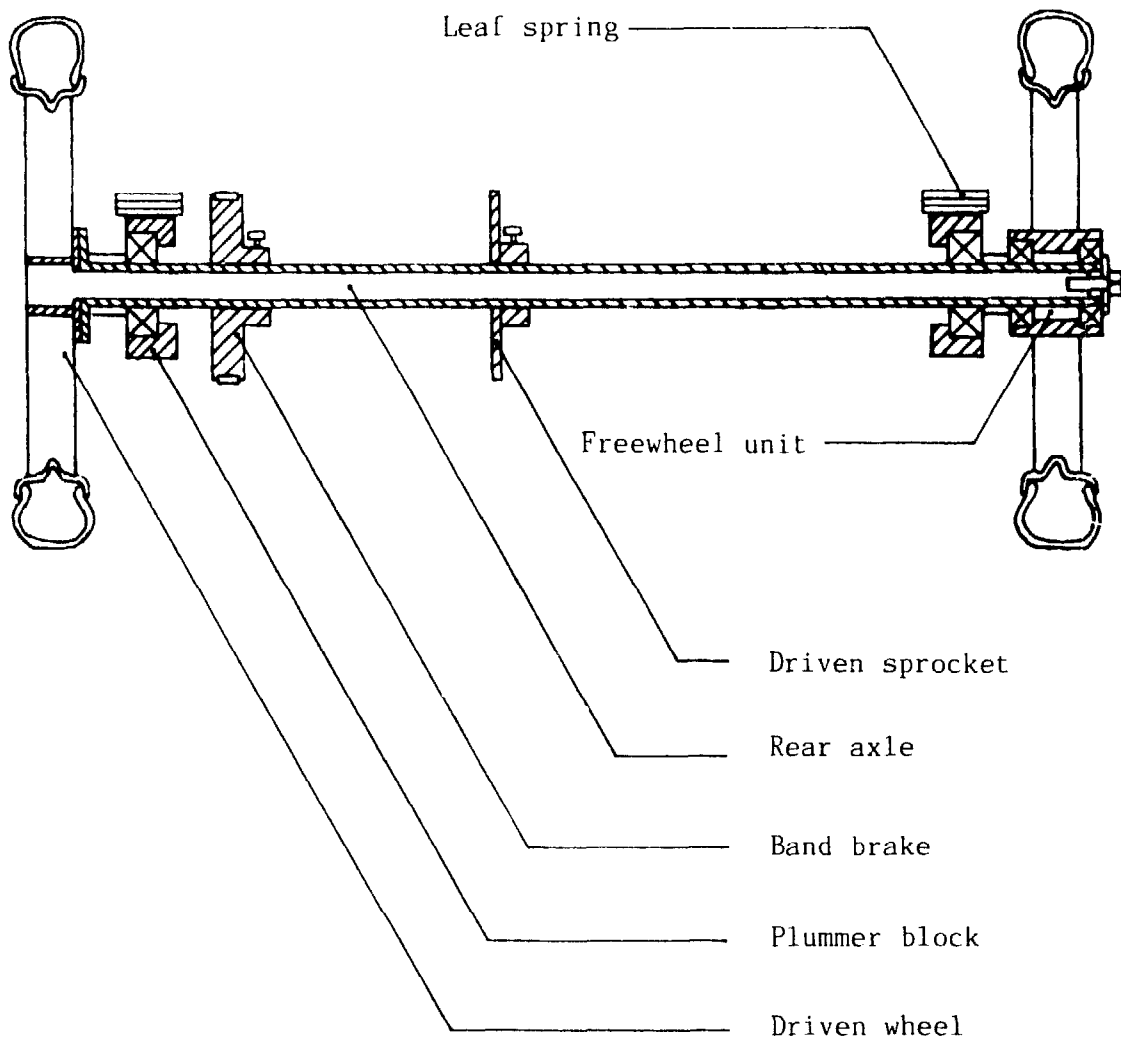


Fig. 4.7 Cross-section of chain-driven live beam axle fitted with band brake

results in the drive sprocket, fitted to the motor cycle gearbox, becoming angularly mis-aligned relative to the driven sprocket fitted to the rear axle. A drive chain cannot tolerate much misalignment without it becoming detached from the rear sprocket or breaking. It is therefore important to limit the suspension movement on a chain-driven rear axle. A spring-loaded chain tensioner, as described near the beginning of this section, will reduce the possibility of the drive chain becoming detached.

Most modern motor cycles feature a 'cush drive' unit in the hub of the rear wheel. This device uses a number of rubber elements to transfer the drive from the sprocket to the rear wheel. The device reduces the harshness of the power transmission and results in better wear characteristics of all the transmission components - especially the chain and sprockets. It is desirable to fit some kind of cush drive unit on the rear axle of a three-wheeled conversion, either by incorporating it in the sprocket mounting boss or in the hub of the driven wheel(s).

For reasons of safety the drive chain of a motor cycle-based three-wheeled vehicle should be shrouded with a guard.

Wheels On a motor cycle based three-wheeled vehicle, the standard front wheel is normally retained. The choice of rear wheels, however, can vary - generally, all the different types of wheels discussed in Annex 5 can be suitable, except truck wheels which are too large.

A lightweight three-wheeler is best fitted with motor cycle- or scooter-type wheels (see Annex 5). Motor car wheels are more suitable for a heavy-duty vehicle; compatible motor car hubs should then be used as discussed in Annex 5.

Scooter-based three-wheelers are usually fitted with scooter-type rear wheels but, theoretically, motor cycle or motor car wheels could also be used.

4.2.6 Brakes

It is recommended that only motor cycles fitted with drum brakes should be used for conversion to three-wheeled vehicles. The front brake of such a motor cycle is actuated by means of a hand lever on the handlebar, through a cable. This can remain unchanged on the converted vehicle. The rear brake of the motor cycle is actuated by a foot pedal through a mechanical rod linkage. This foot pedal can be retained to operate the rear brakes of the converted vehicle, through an extended linkage.

The type of rear wheel brake used is dependent on both the type of wheel/hub used and the transmission system:

1. If motor cycle or scooter wheels/hubs are adapted for use at the rear of the vehicle, their drum brake assemblies can also be converted to operate from the motor cycle mechanical linkage.
2. If motor car hubs are fitted it is possible to use the hydraulic drum brake assemblies by either:
 - (i) fitting a simple hydraulic system with a motor car 'master cylinder' operated by the motor cycle foot pedal; or
 - (ii) retaining a mechanical linkage and converting the drum brakes to cam operation. Note: the mechanism fitted to motor car drum brake assemblies for operating the parking brake is

not usually durable enough to accept the loads required for dynamic braking of a laden vehicle.

3. An exposed chain-driven beam axle without a differential can be fitted with either a band or block brake. Figure 4.7 shows such an axle fitted with a band brake. The brake is connected to the existing mechanical linkage. However, if only one rear wheel is driven and the other revolves freely on the axle to accommodate cornering requirements, then only the fixed wheel will experience braking force. Braking on only one rear wheel requires considerable care to avoid 'locking-up' the wheel and so causing a loss of vehicle stability.

Further information on brakes is given in Annex 6.

4.2.7 Bodywork

The completed vehicle chassis can be fitted with a variety of different types of cargo- and passenger-carrying bodywork which are described in Annex 2.

4.2.8 Lighting system

In most countries, a motorized three-wheeled vehicle is required to display two rear and two brake light units. These lights are easily operated on a motor cycle based vehicle by extending the wires normally used to power the standard lighting. An earth wire, securely attached to the motor cycle frame, is also needed. Turn indicators can be installed just as easily. Rear light units from almost any motor vehicle can be attached to the rear of the vehicle and arranged to illuminate the number plate. Red reflectors should also be mounted at the rear to increase the visibility of the vehicle at night.

4.3 SMALL DIESEL-ENGINEED THREE-WHEELED VEHICLE

4.3.1 Overall configuration

For the same reasons as discussed in Section 4.2.2, this publication concentrates here on diesel-engined three-wheeled vehicles which have two rear wheels and a single front wheel. The main choice in deciding on the overall configuration of the vehicle is to decide whether the engine should drive the front or rear wheels.

The main advantage with driving the front wheel is that the transmission system is very simple and there is no need for a differential unit (see Section 4.2.5). The main disadvantage is that traction will be poorer than if the rear wheels are driven, since the payload is carried behind the driver, and weight is transferred away from the driven wheel under acceleration and when travelling uphill. Thus a front-wheel driven vehicle will be cheaper, but less efficient, than one with rear-wheel driven configuration.

Location of engine If front-wheel drive is used, the engine and transmission should be attached to the sub-assembly supporting the front wheel so that the engine pivots in unison with the wheel when steered (Figure 4.8). This arrangement frees the transmission from any complications due to the operation of the steering mechanism. The engine will normally be

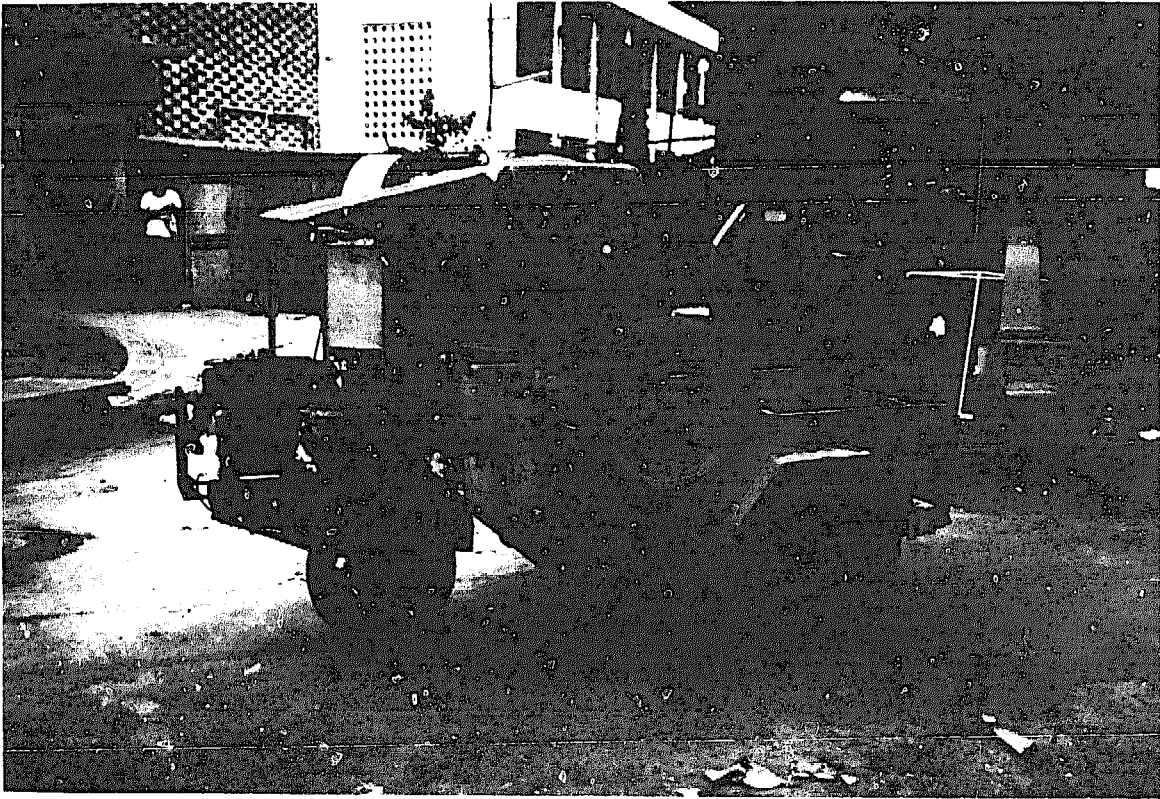


Fig. 4.8 Diesel-engined three-wheeled vehicle with front-mounted engine driving front wheel

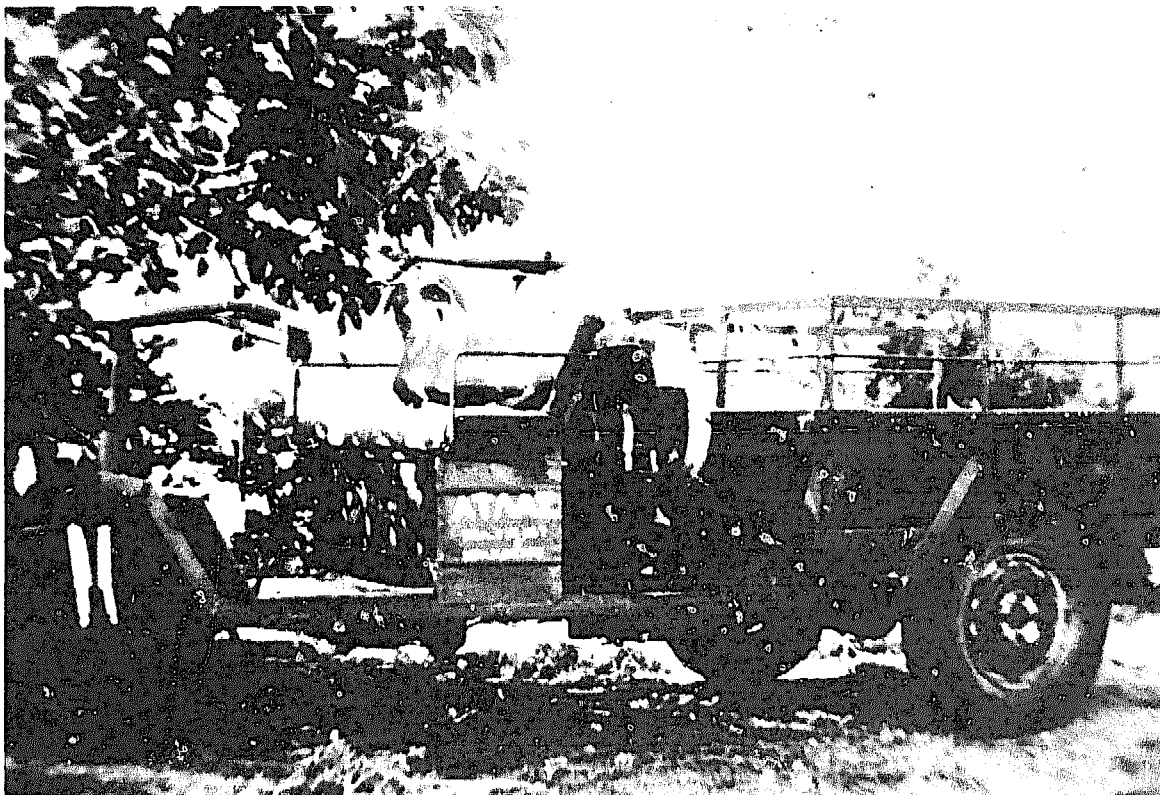


Fig. 4.9 Diesel-engined three-wheeled vehicle with engine mounted in front of load container, driving rear wheels.

located close to, and in front of, the driver.

If rear-wheel drive is used there are a number of possible locations for the engine. The engine can be mounted at axle level, under the load container, or the final drive mechanism can be extended and the engine mounted much higher, in front of the load container (Figure 4.9) or even in front of the driver.

Figure 4.10 shows a vehicle with the engine mounted beneath the load container. The engine has a compact transmission system and drives the rear axle. One advantage of this configuration is that it maximizes the area of the load container. A disadvantage of this design is that the load platform must be placed high which results in a higher centre of gravity for the loaded vehicle and so reduces its stability. Ground clearance beneath the engine may also become limited. If the engine is situated close to the rear axle, the final drive mechanism will be short and this will restrict the movement of the rear axle if suspension is fitted.

Positioning the engine above the rear axle level and near the driver usually involves an additional drive mechanism, typically a belt or chain drive arrangement, which transfers the power to the final drive mechanism. The additional drive mechanism can incorporate a clutch and different gear ratios. Figure 4.11 is a schematic view of a possible engine and transmission configuration.

Overall dimensions The considerations in determining the overall dimensions of the vehicle are essentially the same as those discussed in Section 4.2.3. Chapter 8 features four small diesel-engined vehicles commercially produced by the following companies - Martin Trucks Ltd., Bajaj Tempo Ltd., Trag Project and Scooters India Ltd. The dimensions, weights and payloads of these vehicles will serve as guidelines for a designer considering manufacture of a similar vehicle.

Driver seating The driver's seat should be positioned to allow direct control of the steering mechanism. The driving seat should be high enough to permit good all-round vision from the vehicle. Care should be taken to ensure that the exhaust system directs engine fumes away from the driver and any passengers.

4.3.2 Selection of engine

A single-cylinder diesel engine should normally be selected for this type of vehicle.

Single-cylinder diesel engines are used world-wide for such applications as water pumps, generators and power-tillers. Engines of this type are usually rated by their maximum power output, although the power they can produce for prolonged periods is usually significantly less than the figure shown on the engine plate. For a utility three-wheeled vehicle the engine power rating should not be below 4kW. If it is less the vehicle may not have sufficient power to climb hills, traverse rough ground or carry a significant load. The availability of lightweight diesel engines of power rating over 15kW is relatively poor, and vehicles fitted with larger engines than this cannot be termed 'low cost'. In many developing countries, diesel engines with a power rating of 6-10kW are popular and ideal for fitting to three-wheeled vehicles. Most engines have output shafts with a horizontal axis which is the type required for vehicular use.

It is important to select a model of diesel engine which has a good

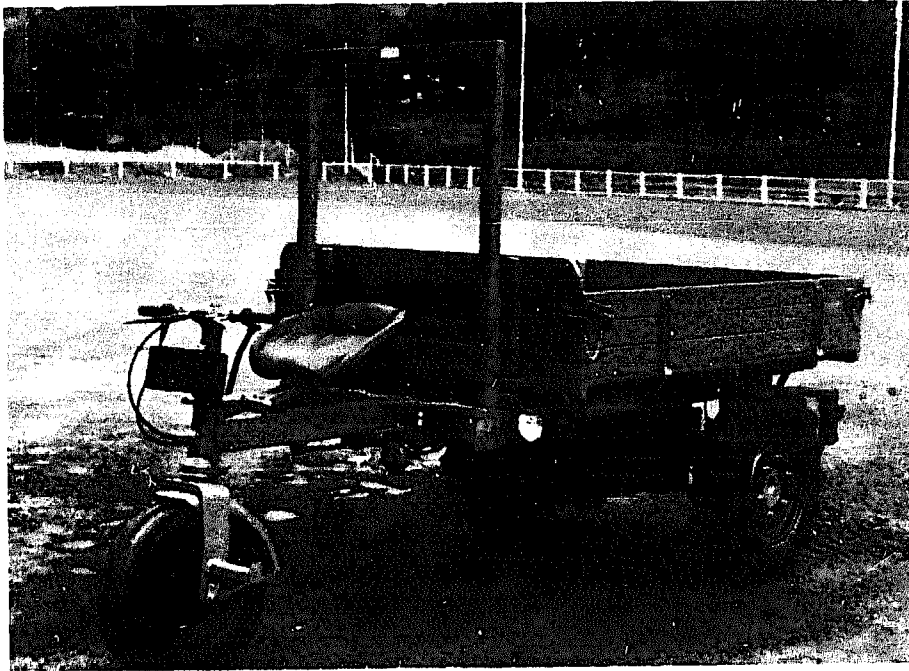


Fig. 4.10 Diesel-engined three-wheeled vehicle with engine mounted beneath the load container

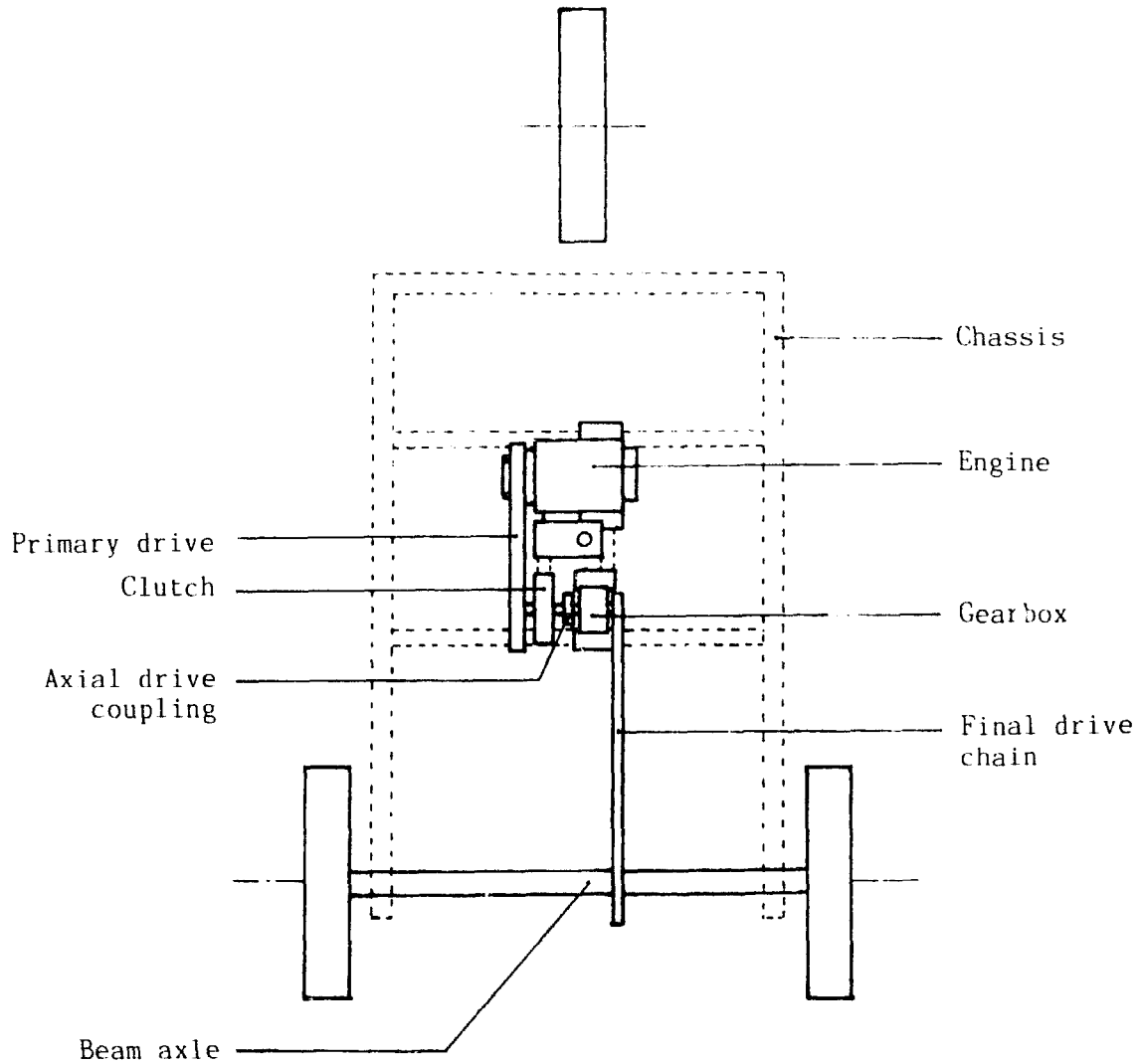


Fig. 4.11 Schematic diagram showing a possible arrangement of engine and transmission

local reputation for robustness and reliability, and for which spare parts are easily available.

Single-cylinder diesel engines are usually made from cast iron and can be air or water cooled. For simplicity, an air-cooled engine is preferred since it eliminates the need for a cooling system. However it is important to ensure that:

- (i) the air-cooled engine will operate for extended periods with a fully loaded vehicle without overheating;
- (ii) the engine is mounted in the vehicle so that it receives an adequate flow of cooling air.

If it is necessary to use a water-cooled engine it is preferable to select a model which has tank cooling, to avoid the need for a radiator/pump cooling system.

Single-cylinder diesel engines are usually equipped to be started by hand with a starting handle, rope or recoil starter. Some feature a battery-powered starter motor, but for a low-cost vehicle this is usually an unnecessary expense. When selecting an engine the direction of rotation should be considered - this is usually anti-clockwise when facing the output shaft. Some engines are equipped with a geared unit which reduces the drive speed of the output shaft. Different engine attachments are often offered by the manufacturers, including a remote throttle control linkage, oil pressure indicator, exhaust extension and shaft coupling units.

4.3.3 Transmission system

The transmission system performs the following functions:

1. To allow disconnection of the engine from the driving wheels. This is necessary to start the engine and to allow it to run whilst the vehicle is at rest.
2. When the engine is running, to enable the drive to be smoothly connected to the driving wheel(s). Both this, and the previous function, are performed by a clutch.
3. To reduce the drive-line speed from that of the engine to that of the driving wheels. The ratio will depend on the relative size of engine, the weight of the vehicle and its desired performance.
4. To enable the ratio of the engine speed and the speed of the driving wheel(s) to be varied. This function is performed by a gearbox.

For a low-cost vehicle, a mechanical transmission system will be used.

General arrangement of transmission The power developed by the engine is transmitted to the driving wheel(s) by a transmission system which consists of a primary drive, clutch, gearbox and final drive. The primary drive transfers power from the engine output shaft to the clutch. With the clutch engaged, power is transmitted through the clutch to the gearbox and final drive to the wheel(s).

The basic elements of the transmission system are illustrated in Figure 4.11.

Clutch The clutch should allow gradual engagement of the drive from the engine and will usually depend on friction for its operation. Three options are possible:

1. The friction-plate clutch is the most popular type used on motor vehicles. It consists of two circular discs which face each other. One disc is driven by the engine's output shaft while the other is attached to a shaft which is connected to the driving wheel(s) via the transmission system. The two discs are gradually brought into contact which creates a frictional force between them that gradually transfers the power from the output shaft to the transmission. Once both plates are rotating at the same speed, the clutch is fully engaged.

The discs are pressed together with a spring which keeps the clutch in constant engagement. To disengage the clutch the discs are separated by pulling one of them back against the pressure of the spring.

A friction-plate clutch is normally operated through a mechanical linkage by a foot pedal or hand lever.

2. The centrifugal clutch automatically engages the drive from the engine at a pre-determined speed. The use of a centrifugal clutch simplifies the control system of the vehicle since there is no separate clutch control - its operation is controlled by engine speed. However centrifugal clutches are best suited to light-duty vehicles and are not recommended for heavier duty diesel-engined three-wheeled vehicles.

3. The tensioned-belt clutch is the simplest and cheapest type and is commonly fitted to small, powered agricultural devices such as single-axle tractors. It is not as efficient as the preceding types of clutch, but it is easily constructed and its performance is adequate for low-cost diesel-engined vehicles.

One or more V-belts are arranged to transfer the drive from a pulley fitted to the engine's output shaft to another shaft connected to the next stage of the transmission system. The belt tension is set deliberately loose but a spring-loaded idler wheel is used to take up the slack in the belt. An example of this arrangement, as used on a single-axle tractor, is shown in Figure 4.12. The drive is disengaged by releasing the pressure of the idler wheel from the belt which allows the belt to become so slack that it is no longer gripped by the engine pulley. This disconnects the drive from the engine. A close-fitting roller or guard should be fitted to the tension side of the belt run to maximize the belt slackness around the disengaged pulleys, and so reduce the tendency of the belt to bind. The drive is re-engaged by allowing the idler wheel to exert force gradually on the belt until it is again gripped by the engine pulley. The movement of the idler wheel is usually controlled by a hand lever.

This type of clutch does not deliver such a smooth power engagement as conventional friction clutches, but the elastic nature of the belt does absorb some of the shock. It is important to specify a heavy duty belt or belts with sufficient capacity to

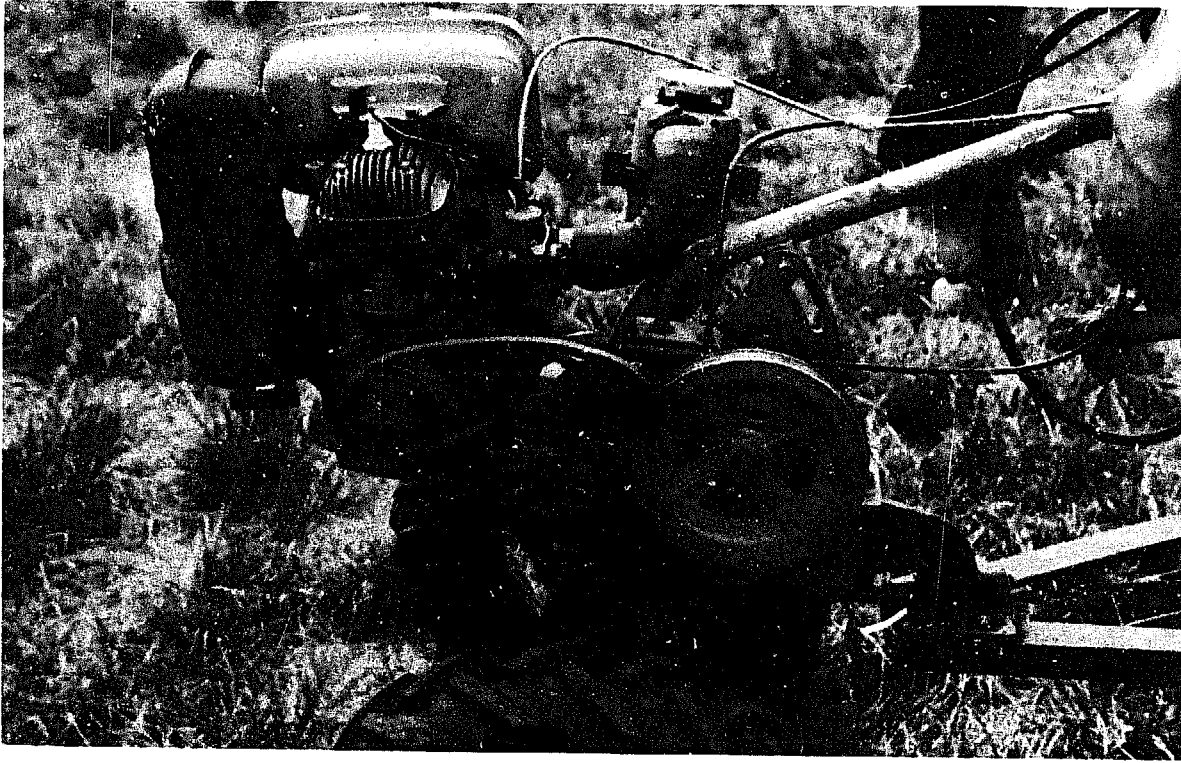


Fig. 4.12 V-belt clutch fitted to single-axle tractor

absorb repeated loadings from clutch operation when the vehicle is fully loaded.

Of the three types described a friction-plate clutch will usually give the best performance. Friction plate clutch mechanisms from motor cars are usually part of the gearbox unit and can be adapted for use with a diesel-engined three-wheeled vehicle. Commercially produced friction-plate and centrifugal clutch mechanisms may be available in some countries. A number of designs exist for producing a simple friction plate clutch but all require the use of a well-equipped workshop with machine tools.

Primary drive The drive can be transmitted from the engine crankshaft to the clutch by the following methods.

1. Flexible coupling The clutch can be driven directly from the engine, with no reduction in speed of rotation, through a shaft. If the clutch is located adjacent to the engine it can be positioned precisely and a rigid shaft coupling used. However, if the engine and clutch are mounted independently on the chassis it is impossible to position them precisely so that the shaft axes coincide. Figure 4.13 shows the three types of misalignment that can occur between the shaft axes. In this situation a flexible coupling must be used to accommodate any misalignment and thus prevent excessive loads being imposed on the shafts and their bearings.

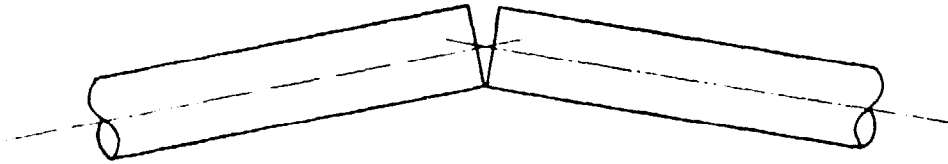
Small diesel engines usually use a flexible coupling unit to transfer the drive from the engine output shaft and many manufacturers supply these to suit individual engines. A locally produced alternative to a commercially produced coupling unit is a flexible-ring joint (Figure 4.14). These are often used to connect shafts between which the misalignment is not very large. The shafts are provided with three-armed flanges, which are bolted to the opposite faces of a flexible ring, the arms of one flange being arranged mid-way between the other. The flexible ring is usually made of one or more rings of rubberized fabric and on a locally produced device these can be layers cut from worn tyres from a motor vehicle. When the shafts are revolving about non-coincident axes there is continuous flexing of the ring. Joints using rubber components assist in smoothing out vibrations.

2. Chain Drive Chain drive is an efficient method of power transmission. It has a number of advantages over direct shaft drive:

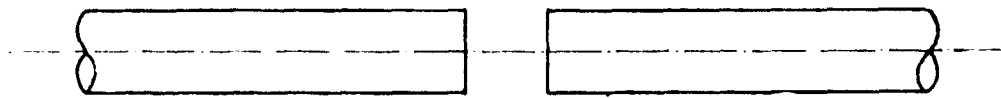
- (i) it allows a reduction in speed of shaft rotation between the engine and clutch, and the sprocket sizes can easily be changed to suit the desired drive ratio;
- (ii) there is a freedom of choice of centre-to-centre distance between the shafts;
- (iii) the chain has enough flexibility to accommodate minor misalignment due to flexing of the vehicle chassis;
- (iv) chains are widely available and sprockets are not difficult to produce using basic machine tools;



Lateral misalignment



Angular misalignment



Axial misalignment

Fig. 4.13 The three possible types of shaft misalignment

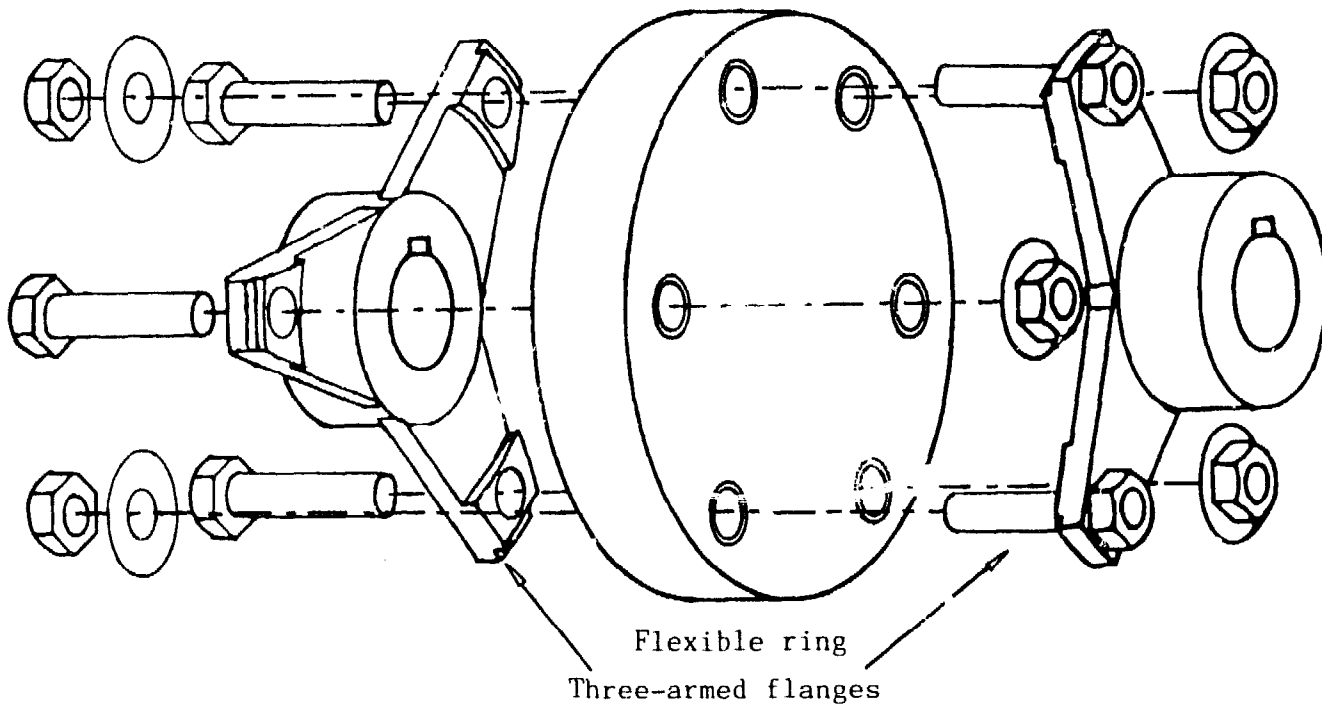


Fig. 4.14 Flexible ring coupling

(v) the elasticity of a drive chain takes up the drive more smoothly than most axial drives.

There are several different types of chain but by far the most widely available is roller chain of single strand. Chains are often specified by their 'pitch' which is the distance between successive links.

When a chain is used to connect the drive from the engine crankshaft to the clutch, it is very important that the chain is of the correct specification with regard to engine speed and power. To maximize the chain service life, the smallest sprocket should have at least 17 teeth. A chain of small pitch is able to run at higher rotational speeds than a chain of large pitch, but can transmit less power. This is why multiple rows of single-stranded chain of small pitch are often used to transmit power from diesel engines. A single strand of standard chain of pitch 12.7mm (1/2") is suitable for a 6kW engine, but two strands of 9.525mm (3/8") chain are preferable, especially at engine speeds of over 2,000rpm. Chain of pitch over 12.7mm should never be run directly from a diesel engine. The drive chain and sprockets should be fully enclosed and continuously lubricated with an oil bath. Mineral oil of medium or light consistency should be used.

The driving and driven shafts should be parallel and the sprockets must be correctly aligned. Sprockets should have tooth shape, thickness, profile, and diameters conforming to the standards required by the chain. Small sprockets are made of steel and should be heat-treated to a hardness of between 250 and 500 Brinell, which is especially important in a high-speed application such as when used on the crankshaft of a diesel engine. Larger sprockets may be made from unhardened steel. The speed ratio is defined as the number of teeth of the driven sprocket divided by the number of teeth of the drive sprocket. In the interests of long life and efficient operation, this ratio should not exceed 6:1.

The centre distance between sprockets should be sufficient to provide approximately 135 degrees minimum arc of meshing of the chain on the smaller sprocket. A means of adjusting the centre distance is recommended, and this is often achieved by slotted holes in the engine mountings. The chain operation can be made quieter and smoother by the fitting of a tensioning device, typically a smooth nylon block, which acts on the outside of the slack run of the chain.

3. V-Belt drive The V-belt is an endless belt constructed from fabric and rubber which has a trapezoidal cross-section. The belt runs on pulleys which have corresponding V-shaped grooves.

V-belt drive has similar advantages to chain drive, but is not as efficient. The performance of different V-belts varies significantly according to the type of materials used and the method of construction. It is therefore very important that the likely performance of a given V-belt is evaluated before specifying its use in a certain application. Standard sizes of belts for power transmission have been adopted and are designated A, B, C, D and E. Because they give low bending stresses as the belt wraps around the pulley, small belts are better for long belt life. However, if small belts are specified it may be necessary to use several in parallel to transmit the required power. This requires a wider pulley which

increases the shaft stresses and bearing loads, all of which raise the cost of the drive. Thus optimum design requires compromises in belt selection. V-belt manufacturers can usually provide the specifications of recommended pulley sizes for a given power and speed requirement. The use of large-diameter pulleys and the corresponding high belt speeds decrease the load on the belts required to transmit the power.

The V-belt drive installation should include some method of adjusting tension on the belts. This is best accomplished by allowing some adjustment of the position for the diesel engine but the use of idler pulleys is acceptable. For reasons of safety, and to protect the drive from water and dirt, a belt guard should always be fitted.

If used as a clutch, as described in the previous section, the V-belt must be of a much more durable type than one used solely for power transmission. In this application, the belt drive combines this function with that of primary drive from engine to gearbox.

4. Gear drive If two adjacent shafts are mounted sufficiently rigidly so that their centre-to-centre distance remains constant and their axes remain parallel, then power can be transmitted between the shafts using gears. Commercially built engines with built-in clutch units, sometimes called unit constructions, often use gears to transfer power from the engine crankshaft to the clutch. Gear drive is not recommended when the engine and clutch unit are mounted independently since small flexings of the mounting frame can result in unacceptable misalignment between gear teeth.

Gearbox A diesel engine produces usable power only within a certain range of engine speeds. This range of engine operating speeds is inadequate for most vehicles. For this reason a series of gears which vary the leverage, or overall drive ratio, between the engine and driving wheels is used to suit varying driving conditions.

A low ratio is defined as one that allows the engine to rotate at a high speed relative to that of the driving wheel(s). The ratio of a transmission system that reduces the drive line speed ten times is numerically denoted as 10:1.

The lowest gear ratio provided need be no lower than is necessary for a start to be made on the steepest gradient envisaged when the vehicle is fully loaded. Depending on the nature of the engine, outside diameter of the tyres and conditions of use, a small diesel-engined vehicle will typically have a total low drive ratio of around 45:1. The engine will be running at its maximum operating speed with the vehicle moving slowly. This performance may be adequate for some applications but the versatility of the vehicle will be very limited. For a small diesel-engined vehicle, three forward drive ratios are considered adequate to provide a satisfactory range of travel speeds. A system that permits the engine to propel the vehicle in the reverse direction is also very useful. The latter is especially important when the vehicle is manoeuvring in a restricted space with a full load.

Many commercial manufacturers of small diesel-engined vehicles fit specially made gearboxes to provide the different drive ratios, but these are rarely available in developing countries. The production of a gearbox requires advanced manufacturing processes and is beyond the capability of most developing country workshops. Some locally produced alternatives do exist, however.

An efficient gearbox for use with a small, diesel-engined, rear wheel drive vehicle can be taken from a motor car. Such a unit usually features a clutch housing and, if the original clutch components are available and in good condition, this combination will give satisfactory performance. However, spare parts for automotive assemblies are usually expensive and often unavailable in developing countries, and this can be a drawback when using components from a motor car. A small diesel-engined vehicle can give good performance by using an adapted motor cycle gearbox and clutch assembly, but the same constraints of availability and cost may apply.

A series of different size pulleys for use with V-belts, known as a stepped pulley system, has been successfully used to give multi-speed drive ratios by several small-scale producers of low-cost vehicles. This system is particularly appropriate where engineering resources are scarce because it can also allow the V-belt drive to operate as a simple clutch (see previous section).

One example of a low-cost vehicle using this technique is the 'Trag' developed by The Office of Creative Ministries of the United Methodist Church (see Chapter 8). Figure 4.15 shows the exposed transmission arrangement of a Trag vehicle. A schematic diagram of the transmission system is shown in Figure 4.16. The output shaft of the engine is factory equipped with a gear reduction unit which reduces the engine speed by a 6:1 ratio. The variable speed portion of the transmission system is made up of an upper and lower set of three pulleys of different ratios (1:2, 1:1, 2:1), with three equal-length V-belts positioned over them. The three corresponding gear levers are positioned on top of the handlebar. When a gear lever is pulled, the spring-loaded idler wheel on the desired belt pushes the belt tight and causes it to grip the pulleys. This results in the desired belt transmitting power while the two other belts remain static. The bottom set of pulleys are mounted on an intermediate shaft, often called a jack-shaft, which drives a roller chain final drive to the front wheel. It is understood that this transmission arrangement, when fitted to Trag vehicles, has given good service in many parts of the world.

Final drive mechanism V-belts can transmit power at high rotational speeds which makes them suitable for being directly driven by a diesel engine, or possibly an intermediate drive coupling, but not for the final drive mechanism of a vehicle.

On a rear wheel drive vehicle the power can be transmitted to the drive wheels by either a shaft or chain. When a rear axle is driven by a shaft then a different type of coupling arrangement from that of the primary drive is usually required. An axle moves relative to the chassis, and this movement may be large if it is mounted on springs. To allow for this movement the drive shaft must be able to accommodate significant changes in length. This is accomplished by the use of a telescopic joint.

The displacements are taken care of by the use of two universal joints connected by an intermediate shaft. A universal joint is used to transmit power between two shafts that are at an angle to each other. Motor car drive shafts, often known as propeller shafts, feature two such joints linked by an intermediate shaft featuring a telescopic joint (see Figure 4.17). The propeller shaft transmits power to the rear axle using a differential unit (see Section 4.2.5). Because universal joints, telescopic joints and differential units are difficult to produce with basic workshop resources, the propeller shaft from a motor car is ideal for

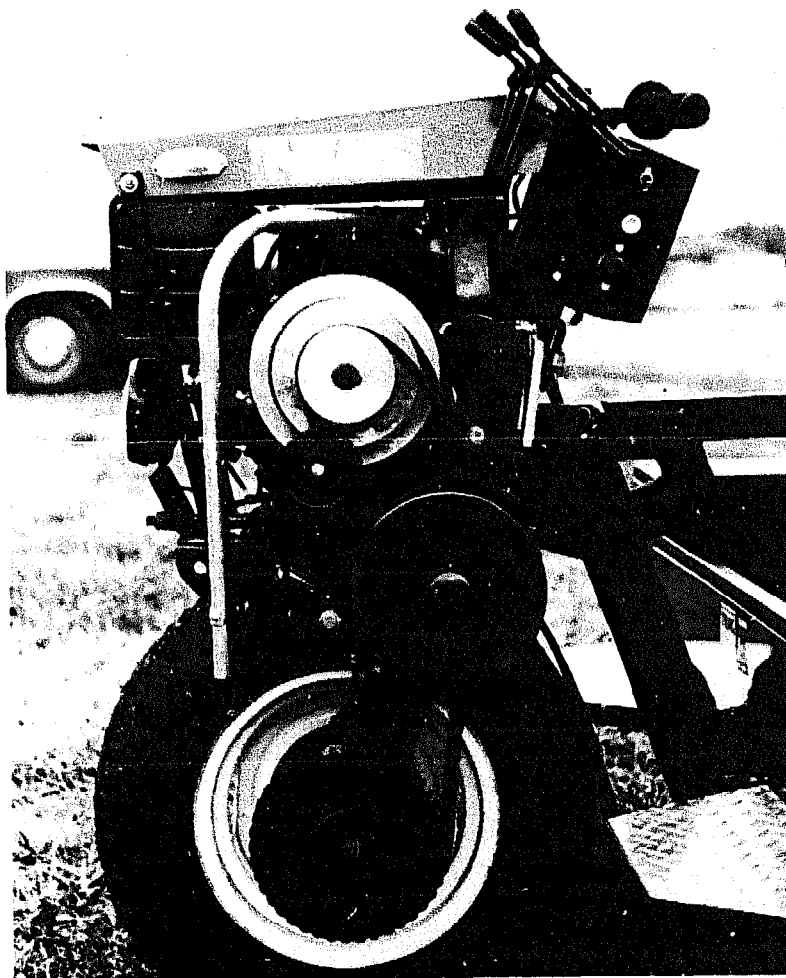


Fig. 4.15 'Trag' three-speed belt drive gearbox

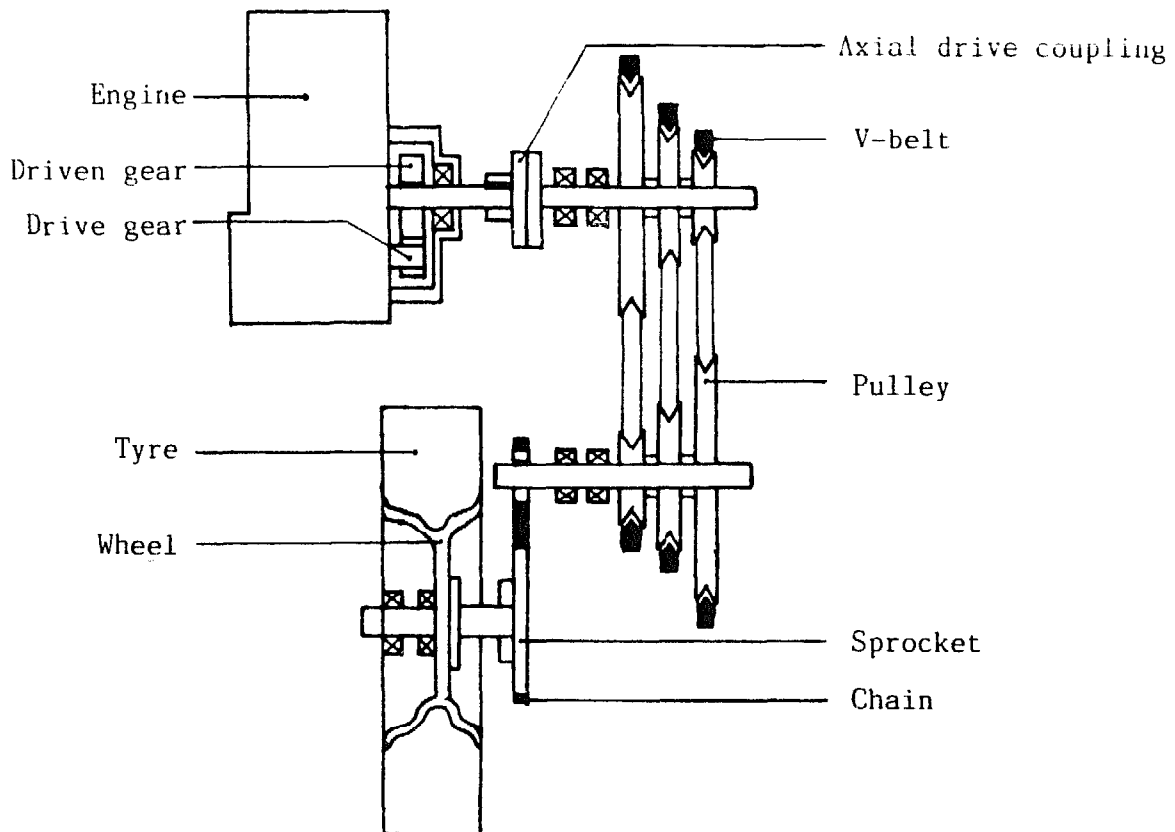


Fig. 4.16 Schematic diagram of 'Trag' three-speed transmission system

adapting to a small diesel-engined vehicle equipped with a motor car rear axle.

As described in Section 4.2.5, a chain-driven rear wheel drive assembly is much simpler than a shaft-driven type but, as explained in Section 4.2.5, it is desirable to fit a differential unit.

A front wheel driven low-cost vehicle will normally feature chain drive to the wheel. A single strand of standard chain of pitch 3/4" (19.05mm) is suitable for either front or rear wheel drive. Some constraints of using chain drive are described earlier in this section, and further discussion on chain-driven wheels can be found in Annex 3. A final drive chain requires regular lubrication, and is best fully enclosed to protect it from dirt which will accelerate wear.

Calculating gear ratios The ratio of engine speed to drive wheel speed is the product of all the different ratios featured in the drive line. If, for example, an engine is connected to the clutch with a drive ratio of 4:1 and the final drive system has a ratio of 5:1 then the total ratio is $4 \times 5 = 20:1$. The addition of a gearbox will vary this ratio.

The speed of a vehicle for a given engine speed can be calculated using the following formula:

$$V = \frac{60 \times N \times (2 \times \text{Rd})}{1000 \times \text{Gr}}$$

Where: V = vehicle speed (km/h)
N = engine rotational speed (rpm)
Gr = overall gear ratio
Rd = drive wheel radius (m)

Example: Suppose a low-cost vehicle is fitted with an engine which produces its maximum power at 2,500rpm. The drive wheels are from a motor car and are of radius 0.25m (including tyre). The desired maximum speed for a particular gear ratio is 30km/h, and it is assumed that the engine has sufficient power to propel the vehicle at this speed.

Therefore: V = 30km/h
N = 2,500rpm
Gr = ?
Rd = 0.25m

$$\text{Rearranging the formula gives: } \text{Gr} = \frac{60 \times N \times (2 \times \text{Rd})}{1000 \times V}$$

$$\text{Gr} = \frac{60 \times 2500 \times (2 \times 0.25)}{1000 \times 30}$$

$$\text{Gr} = 7.85$$

The drive line speed will then be reduced by the ratio 7.85:1.

4.3.4 Chassis, steering and suspension system

Configuration of chassis Chassis materials and construction methods are discussed in Annex 1.

The chassis of a three-wheeled vehicle is generally subjected to less torsional loading (twisting) than that of a four-wheeled vehicle. This enables a simple platform-type design to be used, providing that the main members are of adequate strength.

There are a wide variety of chassis designs used on three-wheeled vehicles. The four frame configurations shown in Figures 3.4 to 3.7 can all be adapted for use on a low-cost three-wheeled vehicle. The main modification required to these frames is the attachment of a steering head to the front of the chassis. The steering head is a steel tube that supports the front wheel sub-assembly in bearings, allowing the vehicle to be steered. Figure 4.17 shows a typical steering head.

The chassis shown in Figure 4.18 has a live rear axle which is the type most used for rear wheel driven vehicles. This axle can be either rigidly attached to the chassis, or supported by sprung members to provide rear suspension for the vehicle.

Front wheel drive vehicles normally have a non-rotating, or 'dead' rear axle. On a low-cost vehicle this axle often acts as the main transverse rear bracing member (Figures 3.4-3.6). If suspension is required, the axle must be independent of the frame and an additional rear bracing member is then required as in the live axle configuration.

Figure 4.18 and the diagrams referred to in Section 3.2.2 show only the basic structure of a low-cost three-wheeled vehicle's chassis. Additional frame members can be added to provide extra reinforcement as required. Diagonal bracing members that are attached between the main frame members are especially effective at improving the stiffness of the chassis. Extra longitudinal members, parallel to, and above the main members and well braced to them, will greatly improve the structural rigidity by forming an open box-type chassis. This type of design gives a very high strength-to-weight ratio, but it significantly complicates the construction and may reduce the vehicle's load-carrying versatility.

Engine mounting The mounting of a small diesel engine to a vehicle is fairly straightforward. All engines feature specially designed mounting points which are usually located at the base. The engine is then bolted to a platform. The frame members of the vehicle that form the platform should be made of steel sections of substantial strength and rigidity. Angle sections of dimensions 38mm x 8mm are suitable for supporting an engine of up to 6kW. To maximize their strength the platform members should be short in length and well supported by the main frame members. Figures 4.11 and 5.3 show schematic arrangements of two possible engine mounting positions. If the engine's output shaft drives a chain or V-belt drive, it is often necessary to make the engine moveable along the axis of the power transmission (see Section 4.3.3). This is most often accomplished by machining slots along the lengths of the engine platform members which allow the engine mounting bolts to slide the engine to the desired position before tightening. Because of the vibration of a single-cylinder diesel engine, spring washers should be fitted to the mounting bolts to prevent them from working loose. Self-locking nuts are also useful in this application.

Rear suspension system The general benefits of suspension and the different options are discussed in Annex 3.

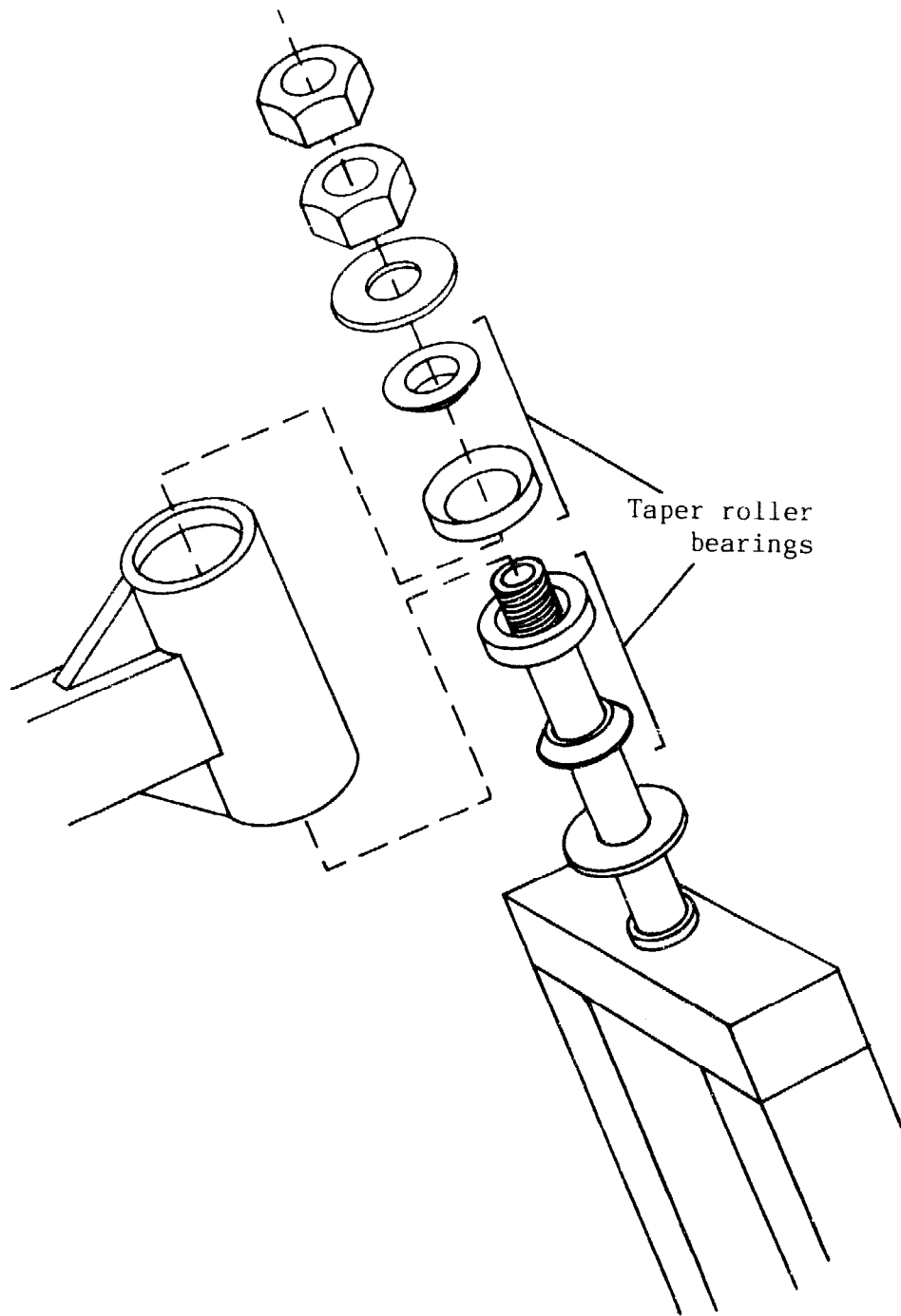


Fig. 4.17 Components of typical steering head assembly

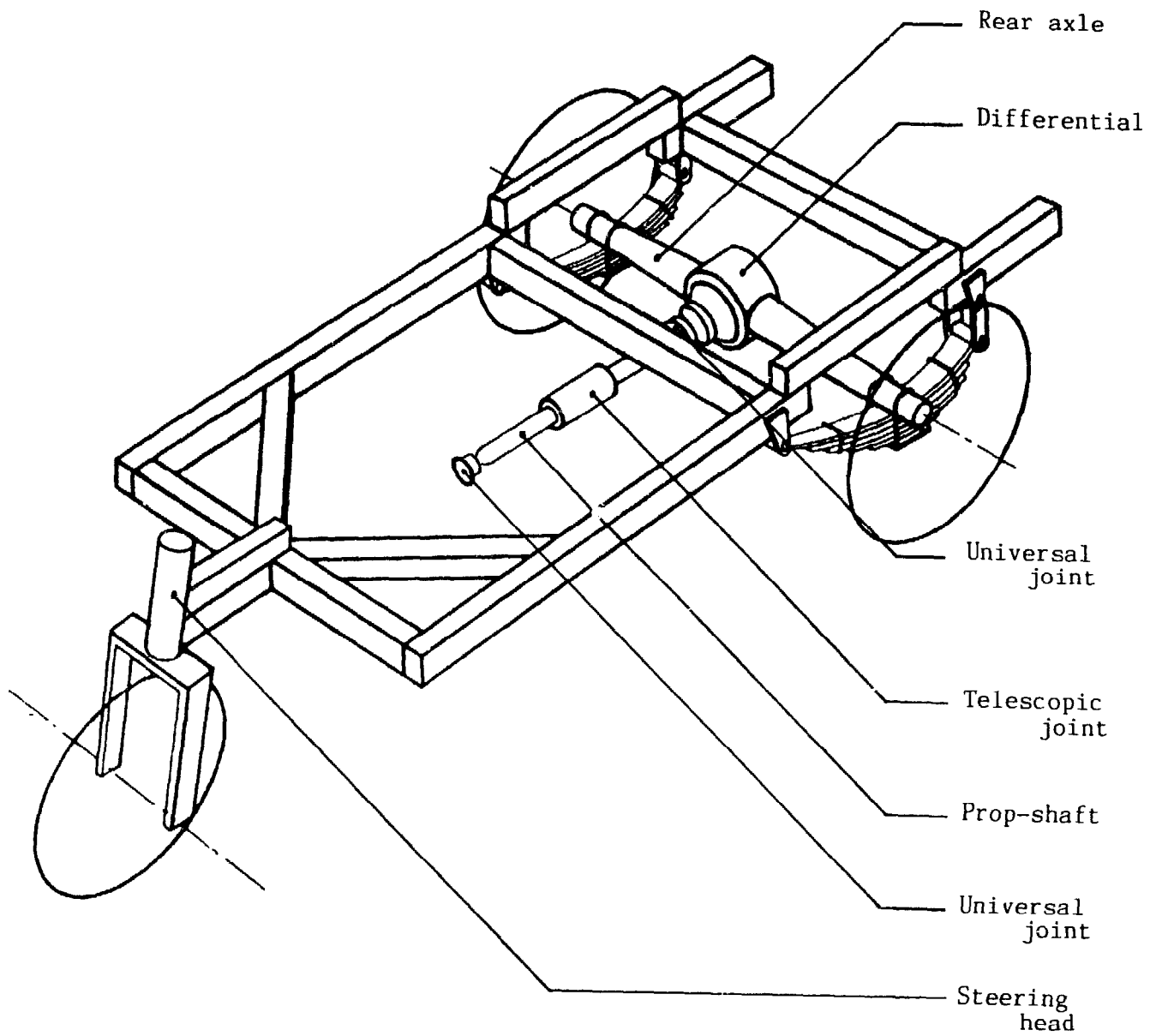


Fig. 4.18 Typical chassis arrangement for three-wheeled vehicle with drive to rear wheels

For a front wheel drive vehicle the most suitable rear suspension systems are:

- beam axle suspended on leaf springs;
- independent trailing arms, possibly using rubber sprung arm units.

(See Section 3.2.2 for further discussion of this).

The specification of the rear suspension system of a rear wheel driven vehicle is significantly constrained by the final drive mechanism. Power is transmitted to the rear wheels of a low-cost vehicle by either shaft or chain drive. Shaft-driven low-cost vehicles require a motor car rear axle which can be attached to the vehicle chassis as discussed in Annex 3. Suitable rear suspension configurations for chain drive are as discussed in Section 4.2.5.

Steering head During normal use, the steering head of a vehicle is subjected to considerable stresses which are constantly varying in magnitude and direction. These stresses become especially severe when the vehicle negotiates uneven ground at speed. For this reason failure of the chassis often occurs in the frame members immediately adjoining the steering head. Careful design is therefore necessary to ensure a strong joint at these points. When welding the steering head tube to the frame, it is vital that there is no lateral twist in the position of the head. This would adversely affect the steering characteristics. Suitable steering angles, or castor angles, are discussed in Annex 4.

A lightweight three-wheeled vehicle can be fitted with the steering head tube from the frame of a scrap motor cycle. The motor cycle's front fork and wheel assembly can then be used in conjunction with this. For heavier-duty applications a fabricated steering head and sub-assembly are required. The steering stem of the sub-assembly must rotate in bearings housed in the steering head tube. Bicycles and many motor cycles use cup and ball type bearings with separate loose balls. However, taper roller bearings give superior performance in this application. Figure 4.17 shows an exploded view of a steering head assembly featuring taper roller bearings. The steering stem has a thread on its top end. This allows the assembly to be clamped together and provides a means of adjustment for the free play of the bearings.

Front suspension system The use of front suspension is not essential but is highly desirable on a vehicle predominantly used to traverse uneven ground. The use of front suspension will usually make the vehicle easier to control. The choice of front suspension configurations for a rear wheel driven vehicle is likely to be between telescopic and leading-link types (see Annex 3). Leading-link types are to be preferred for a fabricated system. They offer better performance on a three-wheeled vehicle and are much easier to produce, although they do depend on the availability of commercially produced damper units.

The choice of front suspension systems is much more limited for front wheel driven vehicles. The chain drive makes the movement of the wheel relative to the engine rather difficult to accommodate and a number of commercially produced front wheel driven three-wheelers have no suspension system fitted. An exception is the Indian 'Bajaj Tempo' vehicle featured in Chapter 8.

4.3.5 Wheels and tyres

The different types of wheels discussed in Annex 5 can all be used on a low-cost, diesel-engined three-wheeler. Motor cycle wheels are only suitable for use on a lightweight vehicle. Scooter wheels are ideal for use on a light vehicle operating in an urban environment where the roads are not too uneven. For general use, and to carry reasonably heavy loads, motor car or fabricated wheels are to be preferred. Small tractor wheels and tyres are excellent for vehicles predominantly used in muddy conditions where ordinary tyres would lose traction.

4.3.6 Brakes

General information on brakes is given in Annex 6. For a rear wheel driven vehicle the rear brake options are essentially as discussed for the motor cycle based three-wheeler in Section 4.2.6. However, if a motor car rear axle is used it is possible to adapt its hydraulic drum brake system.

For a front wheel driven vehicle the rear brake options are as discussed for the trailer in Section 6.3.5.

For a low-speed vehicle it may be possible to avoid fitting a brake to the front wheel. However, for safety it is preferable to have braking on all wheels, and in some countries this may be a legal requirement. If a motor car front hub is fitted, the hydraulic braking system can be used. Flexible hydraulic pipes are used to connect the brakes on the front wheels of motor cars, and these can be adapted to accommodate the steering movement of the front wheel and relative movement due to the operation of a suspension system.

4.3.7 Controls

The means by which the engine, clutch and gearbox are controlled is important to the performance and safety of any vehicle. Driver-operated controls must be efficient and reliable.

Ideally, the operation of starting the engine should be performed from the driver's seat but this is often impractical and not a necessary requirement for a low-cost vehicle. Small diesel engines are usually equipped to be started with a handle, length of rope, or recoil starter. The starting handle and rope methods of starting are the most reliable, and cheapest. Recoil-type starters are more convenient but often give trouble after a certain period of service. Many engines feature a device for enriching the fuel/air mixture prior to starting. It is not usually worth adapting this control for operation from the driving position.

The control used to vary the speed of the engine, called the throttle, must be operable from the driving position. The control is usually a hand lever and is linked to the engine by a cable. For safety, a facility for positively stopping the diesel engine by cutting off the fuel supply should be incorporated.

The clutch mechanism can be cable or rod actuated. Rod linkages are most suitable for operating a V-belt type clutch, and selecting different gear ratios using stepped pulleys.

The control mechanism for operating the gearbox depends largely on the type of gearbox used. Adapted motor car gearboxes usually require positioning that the gear lever is within convenient reach of the driver. The gear lever can be extended in length but linkage systems for

indirectly controlling a conventional motor car gearbox are not usually practical.

4.3.8 Bodywork

The design and construction of different types of cargo- and passenger-carrying bodywork are discussed in Annex 2.

4.3.9 Lighting

To provide for the continuous operation of a lighting system, an electrical generating unit, powered by the engine, is required. Some manufacturers of small diesel engines supply lighting coil units which, when installed on an engine, will generate electrical current for lighting. Another option provided by some manufacturers is the installation of an alternator or dynamo which, when driven by the engine, produces electrical current which can be used to charge a battery. The lighting system is then run direct from the battery. These items are not available in all countries and electrical components adapted from a motor car may be more appropriate for some applications.

The alternator has replaced the dynamo as the electricity generating unit of modern motor cars. It produces usable electrical output over a wider range of rotation speeds and is much lighter. Both alternators and dynamos are usually driven by a V-belt from the motor car engine crankshaft. A similar arrangement can be employed on a small diesel engine using fabricated brackets and pulleys. The pulley sizes must then be calculated to ensure that the diesel engine will drive the generating unit at the desired speed. Figure 4.19 shows output in amperes against the speed in rpm for a typical dynamo and alternator. An alternator generally charges at lower speeds and has a higher output.

An alternator produces alternating current that must be converted into direct current using a rectifier unit before it can be used to charge the battery. Both dynamos and alternators require a voltage regulator unit to prevent over-charging of the battery. These units are fitted to motor cars and can easily be adapted to operate on a small diesel engine powered electrical system which uses a 12-volt motor car battery.

With a continuous output electrical system, standard motor vehicle lights can be fitted to a locally fabricated vehicle, together with other electrical equipment. This may include a horn, driver warning lights, windscreen wipers, etc.

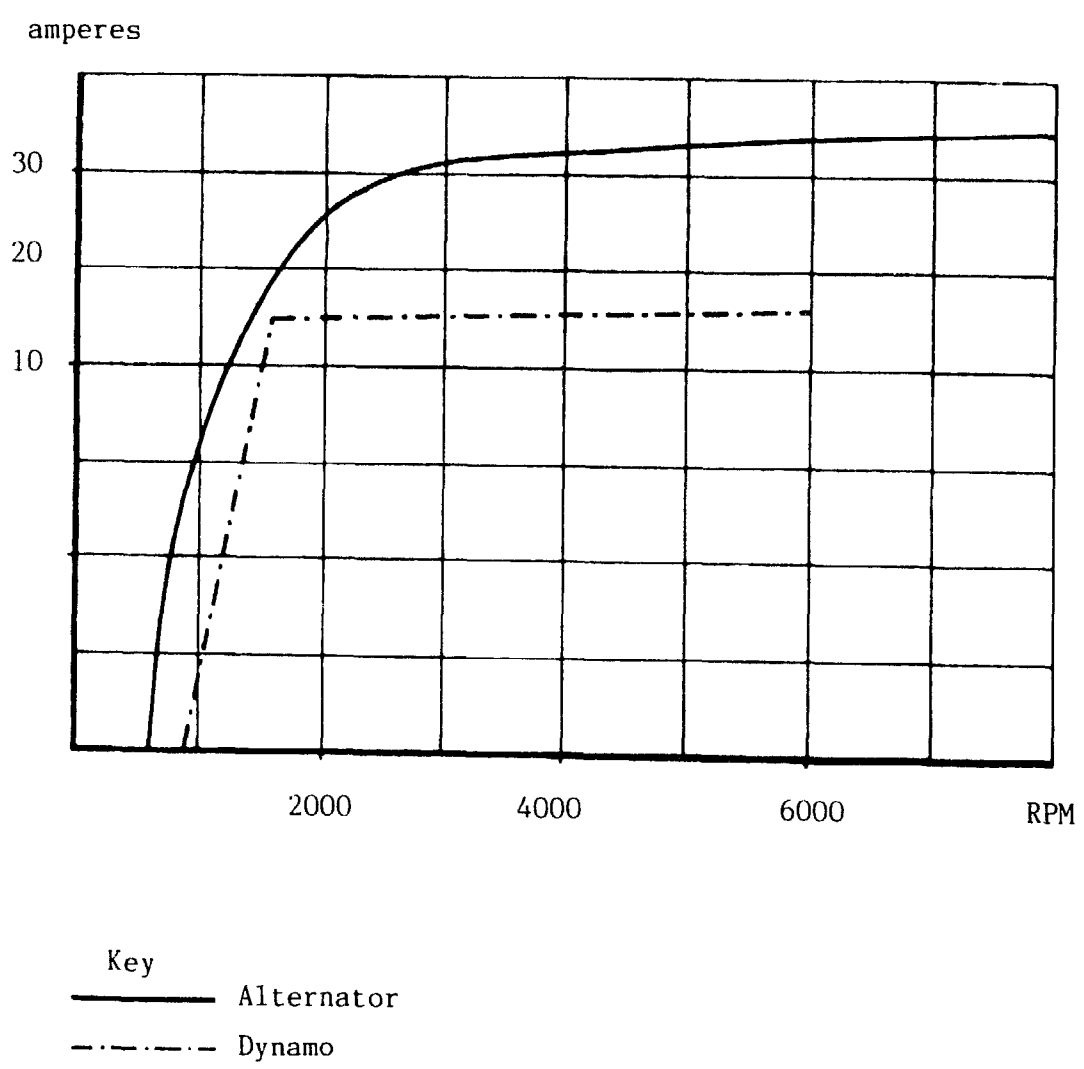


Fig. 4.19 Output versus speed characteristics of typical alternator or dynamo

CHAPTER 5

SMALL-ENGINEED FOUR-WHEELED VEHICLES

5.1 INTRODUCTION

In recent years the use of small-engined, four-wheeled vehicles has evolved in the Republic of Korea and Thailand and they are now manufactured by several small-scale producers in both countries. The salient features of the vehicles, a typical example of which is shown in Figure 5.1, are:

- (i) powered by single-cylinder diesel engine;
- (ii) very simple chassis;
- (iii) very basic bodywork;
- (iv) use of standard automotive transmission, suspension and steering components.

These result in a basic means of transport which provides substantial load-carrying capacity and is cheap to purchase and operate. The vehicles have similar load-carrying capacity to, but lower performance than, conventional light pick-ups. The evolution of these vehicles was dependent on the use of components from scrap vehicles. However, it is becoming increasingly common to base this type of vehicle on commercially available new components such as gearboxes and wheel and axle sets of motor cars.

Concern has been expressed in the countries where they are used that it is difficult to exercise adequate control over the safety of the vehicles and in Thailand there are plans to introduce special legislation covering their design. In producing these vehicles, it is therefore very important to ensure that:

- (i) where components are taken from scrap motor vehicles, they are in sound, safe condition and, if necessary, have been re-conditioned or refurbished;
- (ii) the vehicle has efficient brakes and a safe steering system.

5.2 TECHNICAL DETAILS

5.2.1 Overall configuration

The basic configuration of the vehicle is well illustrated by the examples shown in Figures 5.1 and 5.2. Figure 5.3 is a schematic diagram showing the layout of the major components.

Overall dimensions The overall dimensions are conditioned to some extent by the components used, and the track is determined by the parts selected for the front and rear axles. As a guideline the overall dimensions should be similar to those of a conventional light com-



Fig. 5.1 Typical single-cylinder, diesel-engined four-wheeled vehicle from Thailand.

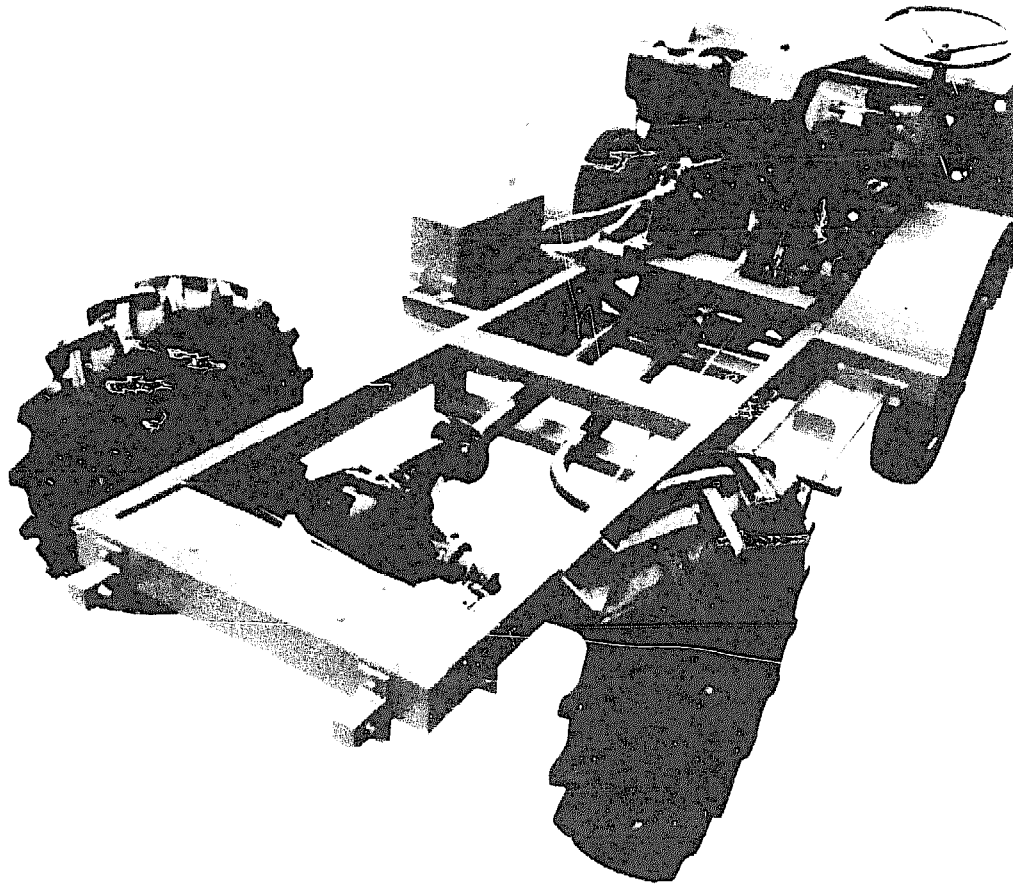


Fig. 5.2 Basic four-wheeled vehicle (without bodywork) with platform chassis constructed from channel section steel

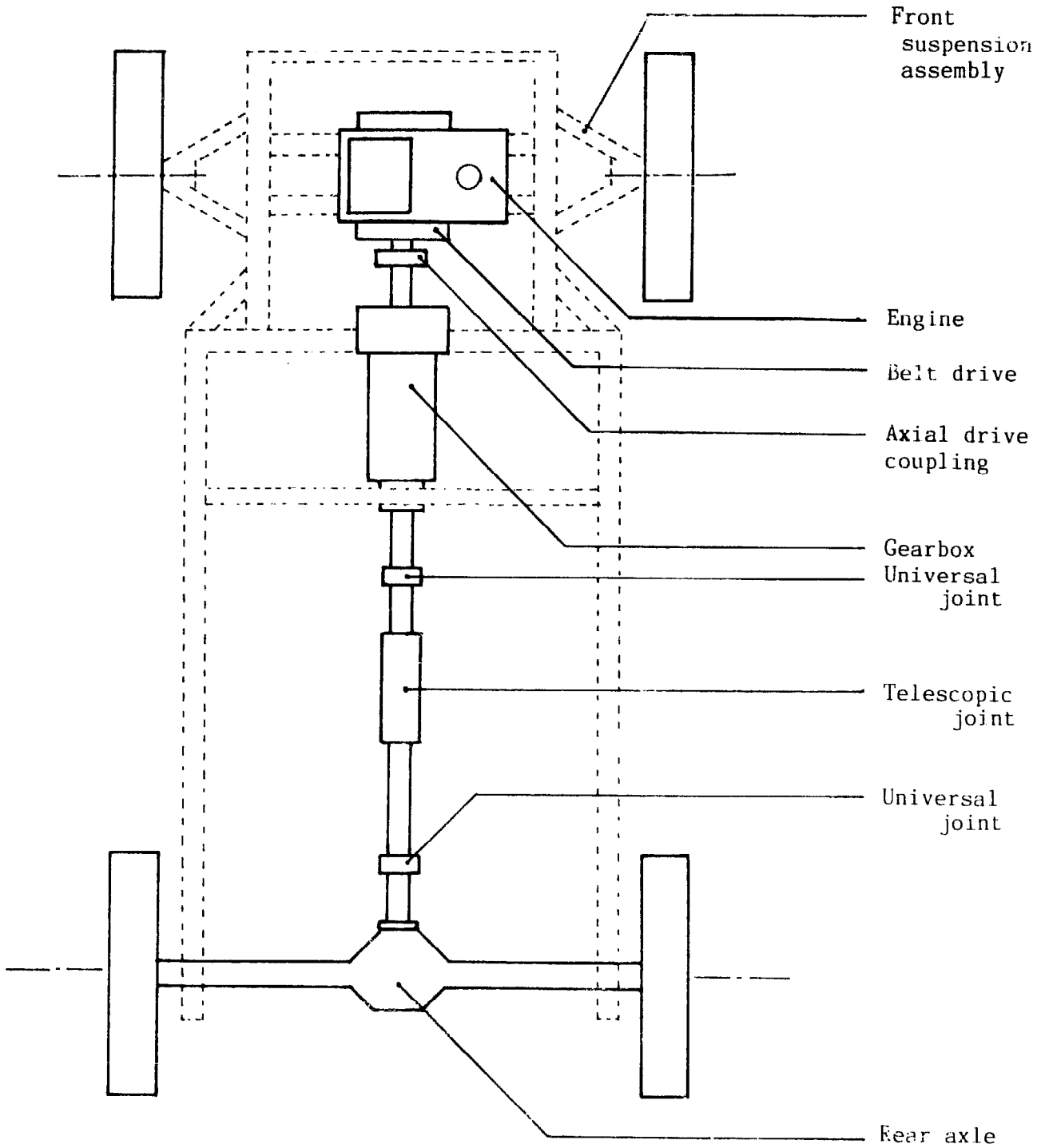


Fig. 5.3 Schematic diagram showing a possible chassis and transmission arrangement

mercial vehicle. The dimensions of the vehicles produced in Thailand are within the following ranges:

Overall length:	4.3-5.6m
Overall width:	1.6-1.75m
Wheelbase:	2.6-3.75m
Track:	1.28-1.32m

Selection of engine The factors determining the choice of single-cylinder diesel engine are essentially the same as for a diesel-engined three-wheeled vehicle, as discussed in Section 4.3. However, given the carrying capacity of which the vehicles are capable, the engine size should be at the higher end of the range of single-cylinder diesel-engines, i.e. 10-20kW. The more powerful the engine, the greater the performance and carrying capacity of the vehicle.

Selection of automotive components In order to facilitate production in hatches, it is important to select components for which there is a ready supply, either from scrap motor vehicles or as new parts. This means selecting components from makes and models of motor vehicle which are widely available in the particular countries. Light commercial vehicles will generally be a better source of components than saloon cars. Thus the aim should be to specify a particular vehicle model as the source of each component so that a standard product can be manufactured. This is preferable to having to adapt the design of the vehicle repeatedly to suit components that happen to become available. The manufacturer using parts from scrap vehicles can either rely on a reputable supplier of components who can guarantee to supply them in sound condition, or take responsibility himself for reconditioning the parts.

5.2.2 Transmission system

Much of the discussion of transmission systems in Chapter 4 is equally relevant to the design of this type of vehicle. Figure 5.3 gives a schematic view of the transmission system.

A vehicle of this type must have a gearbox in order to provide adequate performance. It is possible to use a V-belt drive gearbox, but it is preferable, if the components are available, to use an automotive gearbox. One with three forward speeds, plus reverse, is adequate. The gearbox should be mounted in the chassis so that the gear lever falls conveniently to hand for the driver.

The gearbox will drive through a propeller shaft, incorporating two universal joints, to a live rear axle with a differential unit, the system being based on scrap automotive parts. It may be necessary to shorten the length of the propeller shaft to suit the overall dimensions of the vehicle. If so, this can be done by removing one of the universal joints, cutting off the appropriate length of shaft, and refitting the joint. Any scrap automotive parts used should be checked for condition and renovated where necessary. The most likely requirement will be to replace bearings.

The diesel engine is mounted remote from the gearbox and must be connected to it by a primary drive. The primary drive is preferably by V-belt, and there are three options for this part of the transmission system:

1. Attach the clutch directly to the output shaft of the engine, with a belt drive connecting the clutch to the input shaft of the gearbox.
2. Mount the clutch in unit with the gearbox, with a belt drive from the engine to the clutch input shaft.
3. Connect the engine output shaft to the gearbox input shaft by means of a belt drive which also acts as a clutch (the V-belt drive clutch is described in Chapter 4).

The engine must be oriented so that its output shaft lies in the correct direction for connection to the gearbox by the belt drive. For safety, the belt drive should be securely guarded.

5.2.3 Chassis, suspension and steering

The simplest type of chassis is a flat platform or ladder frame based on two main longitudinal members. This can be seen in Figure 5.1 and Figure 5.2. The frame can be constructed from steel hollow section or heavy-duty channel section and must be cross-braced at intervals along its length (Figure 5.2). Additional brackets and members must be welded to this basic chassis to provide:

1. Mounting points for the front and rear suspensions.
2. A robust platform for mounting the engine. As described in Section 4.3, this mounting should include provision for altering the position of the engine to adjust the belt drive tension.
3. Mounting points for the gearbox. It is desirable to fit rubber pads on the gearbox mountings to isolate vibrations.
4. Mountings for the steering column and steering gears.
5. Mounting for foot pedal controls.
6. Location of fuel tank (Figure 5.2) if this is not integral with the engine (Figure 5.1).

The driver and passenger seating, and the cargo container, are then constructed on this chassis.

Since the vehicle uses a live rear axle with differential, this will be suspended on semi-elliptic leaf springs. The rear axle should be used complete with wheel hubs. If leaf springs, shackles and hubs from scrap vehicles are used, they should be carefully inspected and any worn parts replaced.

Ideally the front suspension and steering systems, including the front wheel hubs, should all be taken from the same model of motor vehicle and fitted as a single unit. It is possible to use independent front suspension, but it is much simpler to attach to the chassis if a dead beam axle, complete with steering pivots and front hubs at each end, is used. This type of axle is most likely to be found on a light commercial vehicle and will normally be suspended on semi-elliptic leaf springs.

Again all components of the front suspension and steering system

should be carefully inspected and worn parts replaced. Particular attention should be paid to all bearings, and to the pivots and ball joints of the steering system.

Standard motor vehicle wheels should be used.

5.2.4 Brakes

As noted earlier, for safety reasons it is important that the vehicle is fitted with efficient brakes on the front and rear wheels. Since the vehicle will use standard motor vehicle hub assemblies, the brakes incorporated in these can be utilized, with a hydraulic operating system using a master cylinder from a motor vehicle. It is essential that the brake components should be carefully inspected and any worn parts replaced. As a matter of course new seals should be fitted in the wheel cylinders and master cylinder.

The existing parking brake mechanism in the rear wheels can be used, operated by a hand lever through a mechanical linkage.

Further information on brake systems can be found in Annex 6.

5.2.5 Bodywork

The bodywork on this type of vehicle is usually very simple, to keep cost to a minimum. In its simplest form (see Figure 5.1) it consists of mudguards over the front wheels, a platform seat for the driver and passengers, and an open-topped cargo container at the rear.

Additional bodywork can be fitted as required, including weather protection for the driver and passengers, and different types of load-carrying container (see Annex 2).

5.2.6 Controls and lighting

The essential driver controls are:

- throttle to control engine speed, normally by means of a hand lever;
- clutch foot pedal or hand lever, depending on the type of clutch used;
- brake operated by a foot pedal, with a separate hand lever for the parking brake;
- gear lever for operating the gearbox;
- steering wheel.

As discussed in Section 4.3, the engine will usually be started by means of a handle, rope or recoil starter.

The minimum lighting requirements are front and rear lights and brake light. It is also desirable, and will be required by law in some countries, to fit turn indicators. The fitting of an electrical system to operate these lights is as described in Section 4.3.9.

CHAPTER 6

TRAILERS FOR SINGLE-AXLE TRACTORS

6.1 INTRODUCTION

This chapter presents information on the design and construction of two-wheeled trailers suitable for use with proprietary makes of single-axle tractor (also known as two-wheeled tractors or power-tillers). Single-axle tractors are becoming increasingly popular for small-scale agriculture in several developing countries and are produced by a large number of manufacturers. The addition of a two-wheeled trailer extends the use of the single-axle tractor as a transportor of goods (and accompanying passengers). A two-wheeled trailer for such a tractor is a relatively simple product to manufacture. There are good opportunities for small-scale industries to produce trailers. This chapter therefore concentrates on simple, basic designs of trailer suitable for production by small-scale industries.

6.2 SINGLE-AXLE TRACTORS

6.2.1 Tractor specifications

The specifications of single-axle tractors vary widely. The most common models feature a single shaft driven from the engine which can be fitted either with rotary cultivator blades for on-field operation, or with a pair of pneumatic-tyred wheels for pulling trailers and trailed implements. Some larger models have two driven wheels plus a separate, independently driven cultivating mechanism.

The single-axle tractors used in developing countries are fitted with either petrol or diesel engines with power outputs typically ranging from 4 to 20kW. The simpler models have a transmission system comprising a V-belt drive using a belt-tensioned clutch, as described in Chapter 4, and with a fully enclosed final drive chain. Many models have only a single speed transmission but some use stepped V-belt pulleys or different-sized chain sprockets to provide a multi-speed system. More advanced models have transmission systems with multi-speed gearboxes, reverse gears and friction plate clutches.

Many single-axle tractors are fitted with two independent steering clutches, one on each driven wheel, which make the tractor easier to steer and manoeuvre. Single-axle tractors are controlled by a handlebar arrangement, as can be seen in Figure 6.1. The clutches, throttle and gear shift lever are all mounted within easy reach of the handlebars. Single-axle tractors are not normally fitted with brakes.

6.2.2 Influence of tractor specification on trailer design

The specification of a particular tractor imposes certain constraints on the design of the trailer to be towed by it. The maximum payload that can be moved on the trailer is determined by the power output of the tractor, the gear ratio(s) and the amount of grip afforded by the tractor's tyres.

Single-axle tractors that are designed to tow trailers have a towing hitch fitted at the rear. The height of the hitch may vary according to the type of tractor and the size of the driving wheels. Because the tractor is able to pivot about the axis of its axle, the hitch and

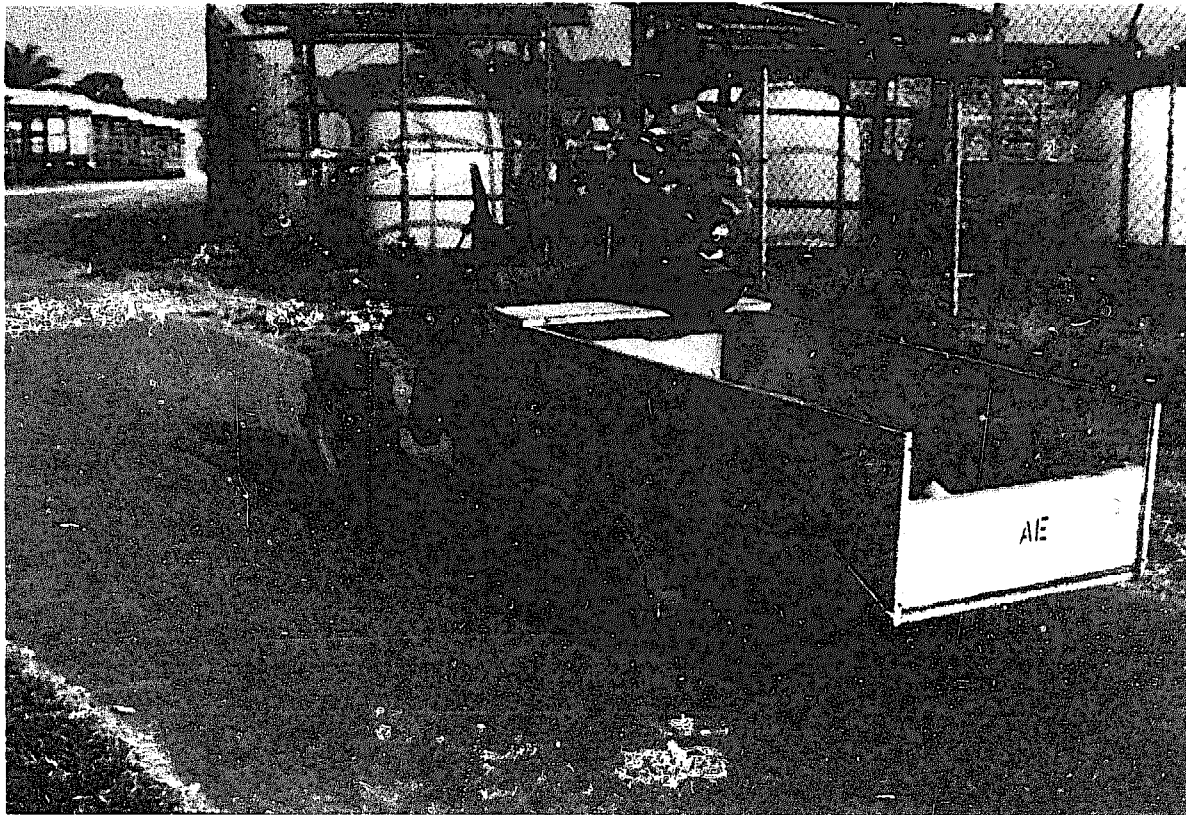


Fig. 6.1 Typical single-axle tractor and trailer. The trailer has a beam axle suspended on leaf springs, and is fitted with block brakes which act directly on the tyres



Fig. 6.2 Single-axle tractor and trailer from China. The trailer has a beam axle suspended on leaf springs, and is fitted with simple bodywork to protect the driver

handlebar heights are affected by the angle at which the tractor is held. When a trailer is attached, this sets the single-axle tractor at a certain angle and therefore determines the position of the handlebars.

The trailer should be designed so that, when hitched to the tractor, the hitch pivot pin is set vertically. This facilitates steering of the vehicle.

6.3 TECHNICAL DETAILS

6.3.1 Overall configuration

The trailer will consist of a chassis and tow bar unit to which is attached a pair of wheels and a load container. The wheels will normally be located either side of the load container, as shown in Figures 6.1, 6.2 and 6.3. This configuration allows large-diameter wheels to be used - which is important when operating in deep mud or on uneven tracks - with a low load platform which contributes to the vehicle's stability and ease of operation. Double-axle trailers are usually designed for loads in excess of 1.5 tonne and are not considered suitable for use with single-axle tractors.

The driver sits on a seat positioned at the front of the load container. The handlebars of the tractor should be arranged to be operated from this position.

The hitch attachment is fitted at the front of the tow bar. The hitch must allow:

- (i) relative movement between the tractor and trailer about a vertical axis when the vehicle is turning a corner;
- (ii) the trailer to twist relative to the tractor when traversing uneven ground.

Figure 6.3 illustrates these requirements. On a single-axle tractor trailer the weight acting on the hitch, sometimes called the 'tongue weight', should be small - usually only enough to prevent the hitch from rattling when traversing rough ground. The weight of the tractor itself is usually sufficient to provide adequate traction of the driving wheels. If the tongue weight is high it will overload the tow bar, badly affect the steering characteristics and cause rapid wear of the hitch. Most trailers for single-axle tractors are therefore designed with the wheels mounted just behind the centre line of the cargo container so that, with an evenly distributed load, there is a small downward force on the hitch.

Dimensions The length of the tow bar is defined by the position of the tractor's handlebars. They should be positioned relative to the driver's seat on the front of the load container to facilitate ease of control of the vehicle.

For a general-purpose trailer, an open box configuration will be the most useful. A rough guide to the box's preferred volumetric capacity is to assume the ratio of 1 cubic metre for 1 tonne payload, e.g. a trailer with a maximum designed payload of 500kg will have a load container of 0.5 cubic metre capacity. Increasing the trailer size - for example by extending the height of the box's sides, may encourage overloading. It is worth emphasizing that, due to poor traction, a tractor/trailer combination has a limited climbing and braking capacity on steep slopes,

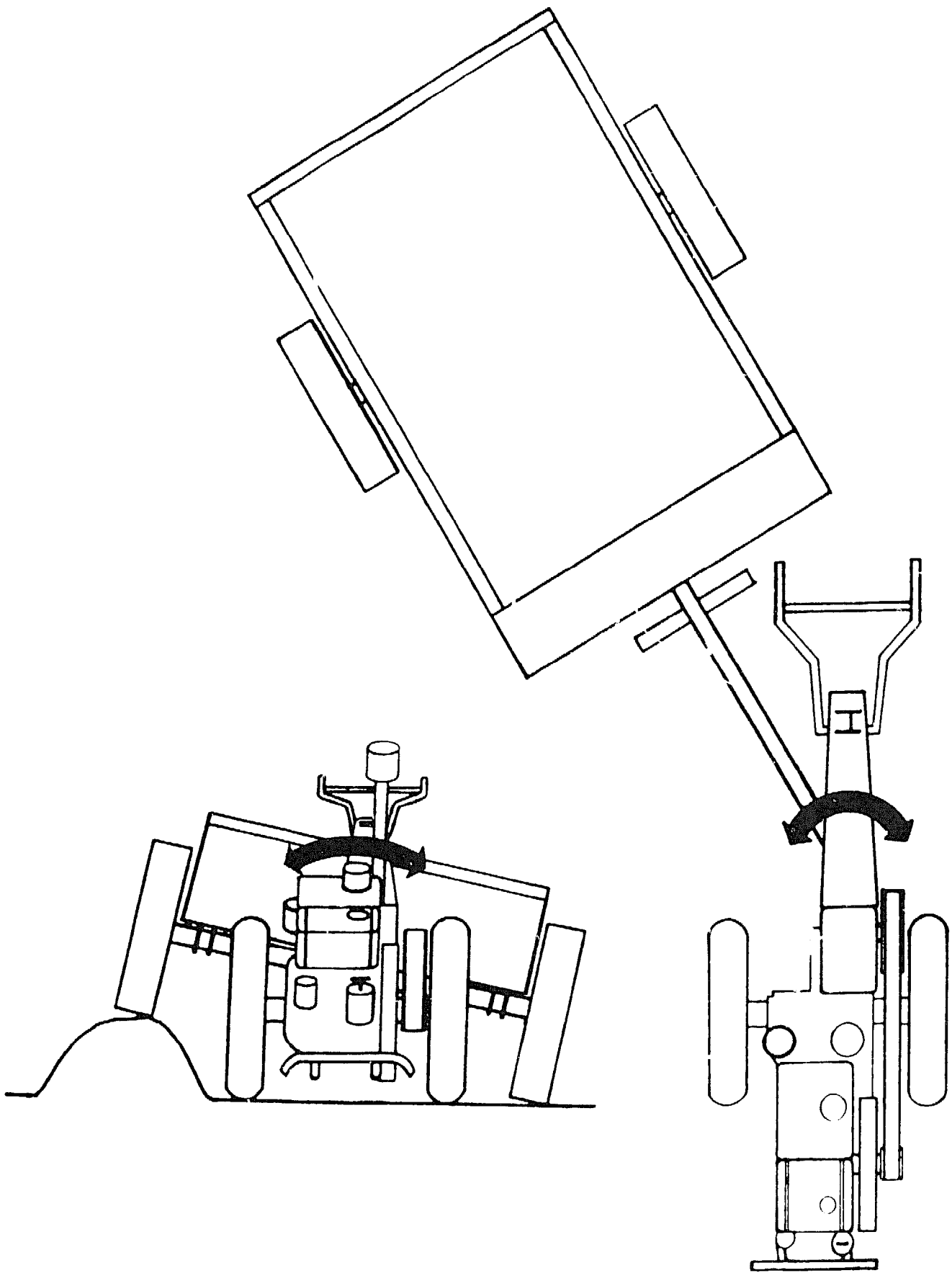


Fig. 6.3 Diagram showing the relative movements that the hitch mechanism must allow between the single-axle tractor and the trailer

especially in slippery conditions. It is thus important not to make the trailer unnecessarily large.

Figure 6.4 gives a range of suggested dimensions for trailers of different load capacities.

6.3.2 Chassis

The trailer chassis provides a strong structure to support the load on the vehicle, and for attaching the cargo container. The basic chassis configurations, discussed in Section 3.2.2 on motor cycle trailers, are also suitable for trailers designed to be towed by single-axle tractors, with the exception of those designs using motor cycle wheels.

The chassis of a trailer is normally fabricated from steel sections which are welded or bolted together. The structural design of the trailer and the specification of the steel sections will vary according to the weight to be carried, conditions of use and available resources. Annex 1 discusses chassis construction.

6.3.3 Suspension system

The general benefits of using a suspension system on a vehicle, together with descriptions of different types, are discussed in Annex 3. A suspension system is not as important on a single-axle tractor/trailer as on other motorized vehicles, however. This is because the trailer is towed relatively slowly, is usually used for the transportation of goods rather than passengers, and usually uses motor car-type wheels and tyres which give a reasonable degree of shock absorption. Also, the tractor/trailer combination is fairly stable at low speeds and its controllability will not be greatly improved by the fitting of suspension to the trailer.

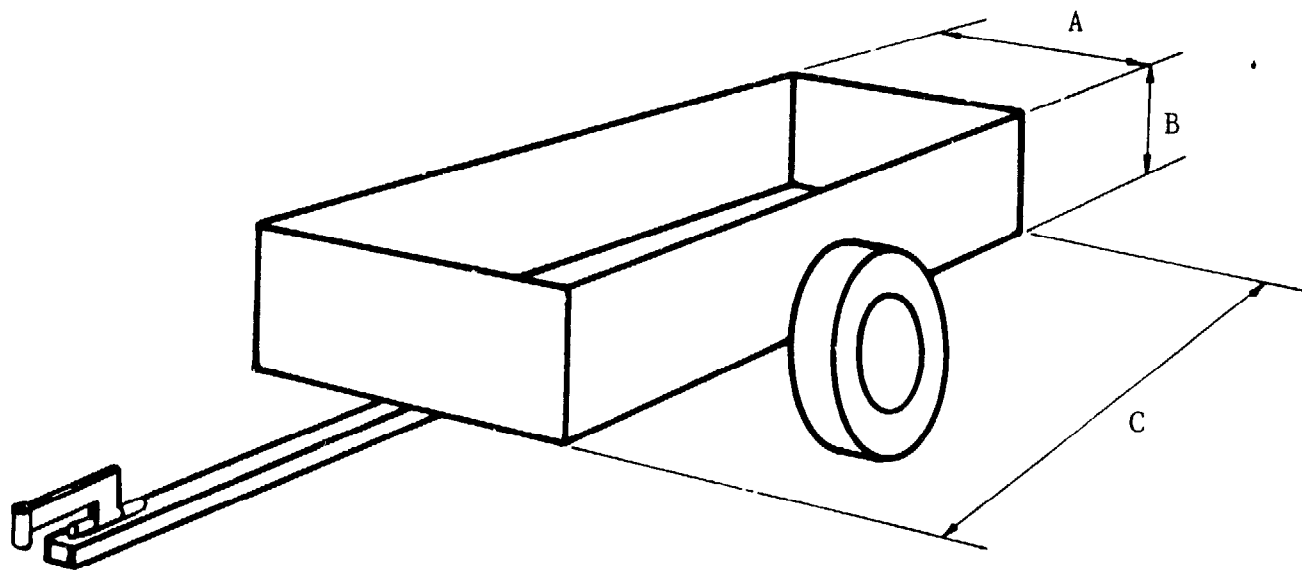
The comfort of the driver of the tractor/trailer will, however, be improved by the addition of a suspension system, and the stresses on the vehicle structure will also be reduced. This is of particular importance in the case of a heavily laden trailer going over rough ground. In common with other vehicles, a suspension system is desirable if the trailer is frequently used to transport passengers.

The simplest and most common form of suspension system for the trailer of a single-axle tractor is a dead beam axle supported on a pair of leaf springs. The trailers shown in Figures 6.1 and 6.2 use this type of suspension system. The other alternative, depending on the availability of components, is to use trailing arm independent suspension - rubber-sprung arms of the 'Indespension' type are very suitable for trailers. More detailed information on these suspension systems is given in Annex 3.

6.3.4 Wheels and hubs

The trailer wheels should be fitted with pneumatic tyres of the type and size used on motor cars, mounted on hubs welded to a beam axle or supported on trailing arms. The most likely sources of wheel and hub components for the trailer are:

- proprietary hubs, axle assemblies and wheels (which accept standard automotive tyre sizes) produced for trailers (these are often of different specification from motor car components);



Maximum Payload (kg)	Dimensions (mm)		
	A	B	C
250	790	220	1,390
500	1,000	280	1,750
750	1,200	320	1,980
1,000	1,260	350	2,200
1,500	1,400	430	2,500

Fig. 6.4 Typical dimensions for the load container of a trailer for a single-axle tractor

- proprietary hubs, axle assemblies and wheels produced for motor vehicles;
- components from scrap motor vehicles.

However, it is feasible to produce hubs and wheels on a small scale specifically for trailers for low-speed vehicles, as discussed in Annex 5.

6.3.5 Brakes

Since single-axle tractors do not usually have brakes, they must be fitted to the trailer. The most sensible braking system for a trailer is to have a brake fitted to each of the two wheels operated by a mechanical linkage (either rods or cables) actuated by a foot pedal or hand lever. The linkage should have provision for retaining the brakes in the 'on' position to act as a parking brake.

Proprietary wheel/axle assemblies are available complete with mechanically operated drum brakes. If hubs from scrap motor vehicles are used for the trailer, it is sensible to select hubs which include the drum brake assemblies. These drum brakes can be simply adapted for mechanical operation. Block brakes are suitable for low-speed trailers. A simple method of installation is to weld a circular drum to the inner face of each wheel against which the blocks can act. Crude block brakes that force a block on to the tread of the tyre, as shown in Figure 6.1, are not as effective, but their use is preferable to having a completely unbraked trailer.

Further information on brakes is given in Annex 6.

6.3.6 Hitch mechanism

The hitch mechanism of a single-axle tractor/trailer is unusual in that it should only allow for rotation about two axes as shown in Figure 6.3. The hitch must prevent any movement about the lateral horizontal axis so that the tractor and trailer form, in effect, a semi-rigid chassis.

The hitch mechanism must also allow the trailer to be attached to, or detached from, the tractor quickly, safely and easily. This function is important to the versatility and convenience of the tractor. Ideally the method of attaching/detaching should not require the use of any tools, and should not involve removing any parts of the hitch for any length of time, as these may be mislaid.

A typical hitch, as used in many parts of Asia, is shown in Figure 6.5. An adjustable version of this, suitable for different heights of hitch point, is shown in Figure 6.6. The hitch itself is attached to the tractor and secured by a pin as shown.

Standard dimensions for the hitch point on single-axle tractors have been defined by the Japanese and are widely used by both tractor and trailer manufacturers. Figure 6.7 shows the dimensions of a standard hitch point based on Japanese specifications.

The hitch is subjected to considerable loads in use and this necessitates a robust design made from steel.

6.3.7 Bodywork

The fundamental bodywork requirements for a single-axle trailer are a load platform or container and a seat for the driver. Load containers and different bodywork arrangements are discussed in Annex 2. A typical

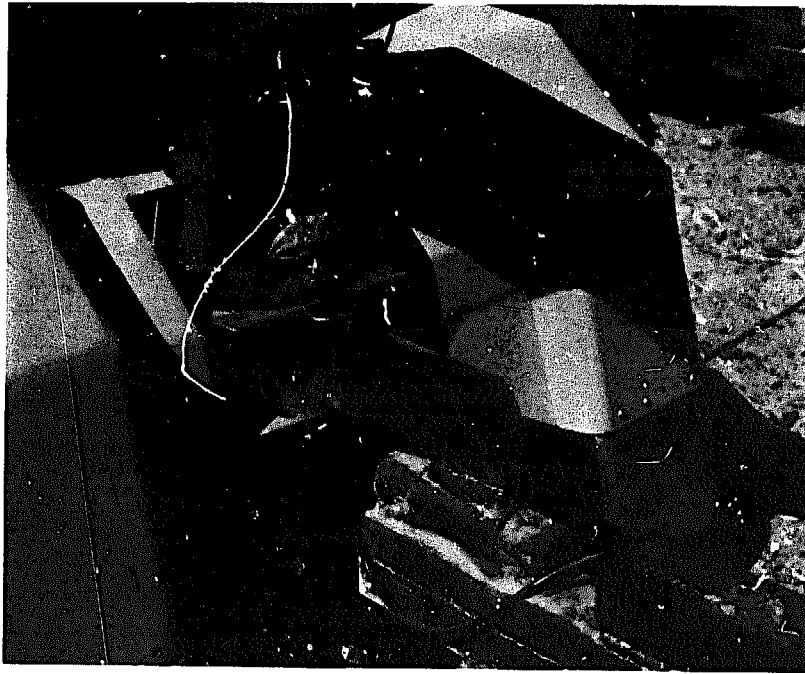


Fig. 6.5 Typical single-axle tractor and trailer hitch

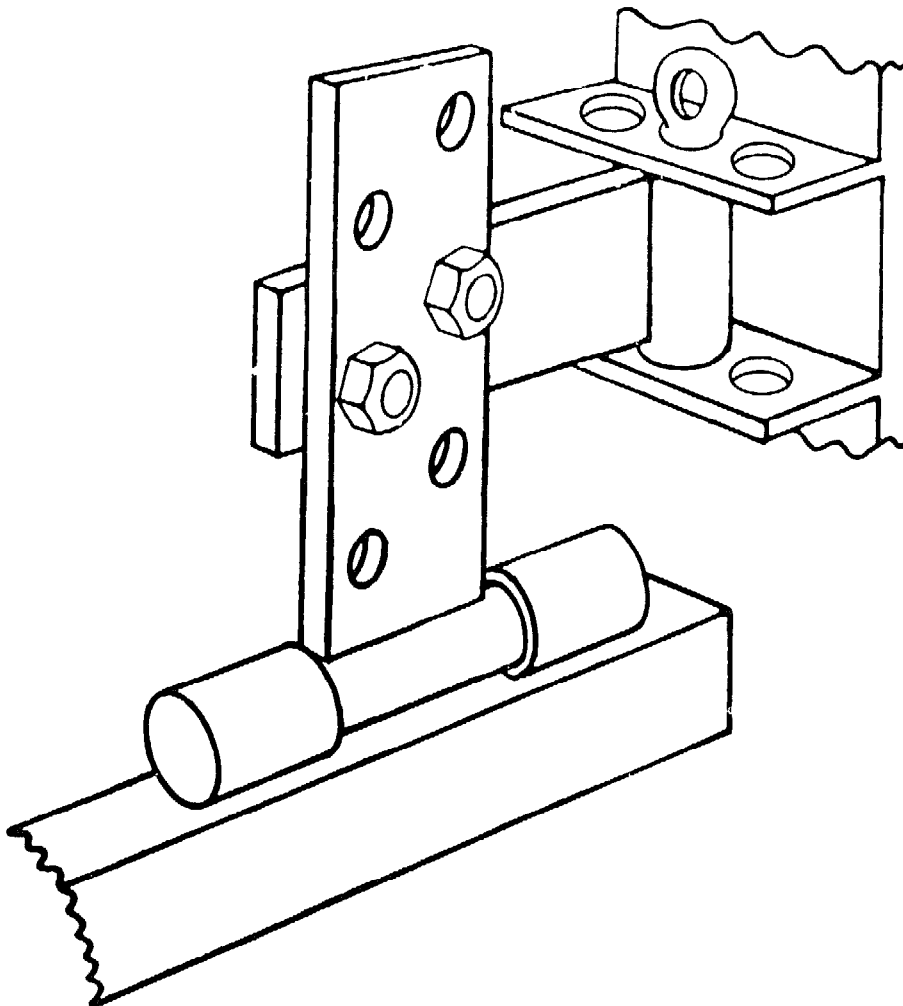


Fig. 6.6 Trailer hitch with provision for height adjustment

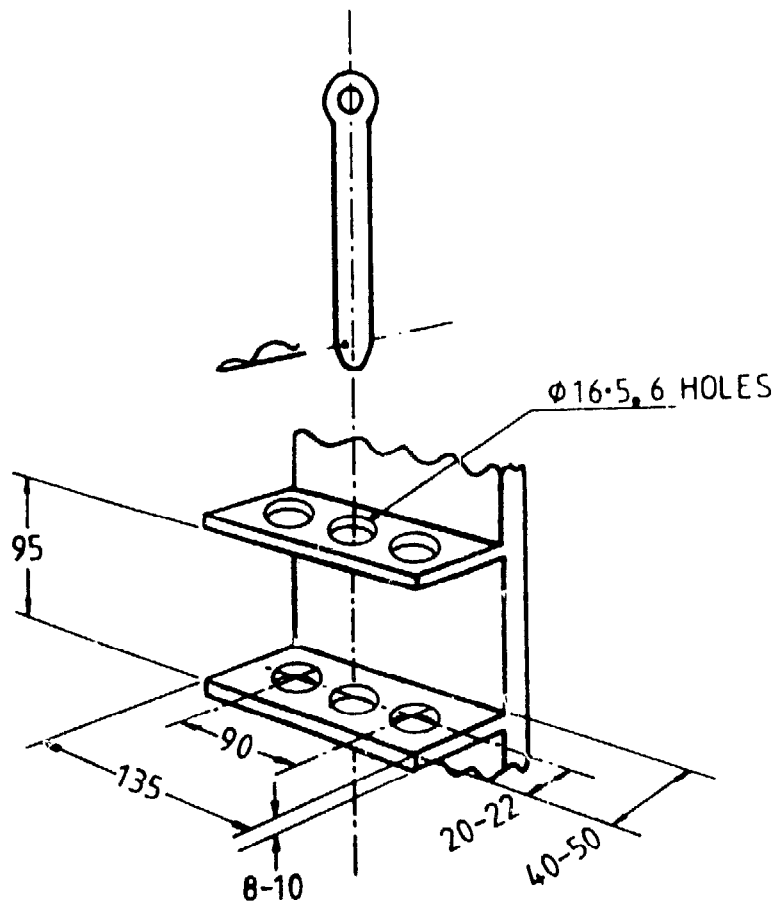


Fig. 6.7 Japanese standard hitch dimensions

trailer will feature mudguards and a bench driving seat with a back-rest. Figure 6.2 shows a commercial example with a sun-shade and small cupboards fitted underneath the seat.

6.3.8 Lighting

In a number of developing country situations, single-axle tractors and trailers are used on public roads without lights. In many countries, however, the fitting of front, rear and brake lights is a legal requirement for all motorized vehicles and they are essential if the vehicle is to be used in the dark. Some single-axle tractors have a headlight fitted as standard equipment - powered by an engine-driven lighting coil unit. With this equipment, rear lighting can be powered by connecting wires to the lighting coil unit's output terminals.

Many single-axle tractors are not equipped with a lighting coil unit and often do not have provision for the attachment of one. In this case, one option is to attach the alternator from a motor car to the engine, as discussed in Section 4.3.9. The battery can then be carried in the trailer.

CHAPTER 7

MANUFACTURING ASPECTS

Previous chapters discuss in detail the design of different types of low-cost motorized vehicle. Certain aspects of manufacture are considered in these chapters, because of their relevance to the design process. This chapter is concerned with the organization, management and production engineering aspects of manufacture. It presents various methods of improving production efficiency to increase productivity, reduce costs, and achieve good product quality. Finally, the chapter analyses the breakdown of manufacturing costs, and discusses the considerations involved in setting sales prices.

7.1 METHODS AND SCALE OF PRODUCTION

The manufacture of low-cost motorized vehicles involves a range of different manufacturing processes. Although it is assumed that small or medium-scale industries will not produce their own major components such as engines and gearboxes, manufacture of the range of vehicles covered in this book still involves:

- metal fabrication skills for the production of vehicle chassis;
- body construction facilities, including metal, timber working, upholstery and painting skills, for the production of different types of passenger body and cargo container;
- lathe turning, and other machining and metal processing facilities for the production of a variety of smaller components used in the vehicles.

Individual manufacturers must decide whether to produce all vehicle components, encompassing the range of skills defined above, 'in house' or to sub-contract some activities to specialized industries. Where the products utilize components from scrap motor vehicles, the industry must decide whether to take responsibility for refurbishment of these parts, or to rely on the suppliers to supply them in renovated condition.

Throughout the technical chapters, emphasis has been placed on the manufacture of a standard product, or limited range of standard products. This allows efficient production procedures to be used, good quality to be maintained, and sales prices to be kept to a minimum. It will therefore serve to increase the size of the market for the vehicles by keeping prices low. The alternative is to produce vehicles on a 'one-off' basis to meet individual customer requirements, but this increases administrative difficulties, results in high overhead costs, and means that production output will be low.

Given the skills required, and the need to make standard products, manufacture of low-cost vehicles is most likely to be on a batch production basis by small or medium-scale industries in urban areas. It is on this type of industry that the technical chapters of this publication are focused. However, there is also potential in certain situations for centralized, large-scale production, most probably for some of the vehicles described in Chapter 8. The characteristics of these two scales of production are described below.

7.1.1 Small and medium-scale industries

Small and medium-scale industries are characterized by the use of electrically powered equipment for the basic metal machining, forming and fabrication activities, and for processing of timber and other materials. An industry of this level will normally only be able to cater to the market for low-cost motorized vehicles in its own region of the country. The industry is likely to be capable of producing a range of related vehicles, and may also manufacture other products requiring similar production processes. Small- and medium-scale industries would normally buy in the more complex and specialized components, either as new parts or from scrap motor vehicles.

Advantages of this level of production include:

- resources and expertise available to achieve good-quality construction and often to develop, adapt and improve designs;
- use of machinery and special tooling enables high productivity of labour to be achieved;
- responsive to local requirements - geographic decentralization enables the manufacturer to adapt designs to suit regional conditions;
- formal organization facilitates use of outside expertise and assistance;
- resources available to market vehicles effectively and promote their use;
- control over raw material and component supplies and prices.

Disadvantages of this type of production include:

- possible distribution difficulties and high cost of transport to customer (dependent on production volume relative to geographic extent and size of local demand);
- repair service limited to nearby users unless the manufacturer develops a marketing network through distributors or dealers;
- machinery and materials often imported and may be difficult and/or expensive to obtain in some circumstances.

7.1.2 Large-scale centralized industry

This type of industry has the potential to achieve high quality production at low unit cost by using high-capacity machinery. However, achieving this potential is very dependent on the efficient organization and management of human, capital, financial and material resources, and on there being sufficient market demand for the plant to operate at high capacity. A large-scale industry would be able to produce more complex components which are beyond the capability of smaller manufacturers. It might enter into a licensing agreement for local manufacture of low-cost vehicles from an overseas source of technology, for example. One would not expect a large-scale industry to utilize components from scrap motor vehicles in its products.

Advantages of large-scale production include:

- economies of scale and high productivity of labour possible (but not always achieved);

- resources and expertise available to develop, adapt and improve designs and achieve good-quality construction;
- resources available, including possible government backing, to promote use and sales of vehicles;
- control of local raw material supplies possible - will also have better access to imported supplies than smaller-scale industries.

Disadvantages of large-scale production include:

- difficult to obtain feedback from users - may inhibit improvement and innovation;
- marketing, distribution and servicing organization required;
- high cost of transport to customer (for complete vehicles);
- large capital investment required, often for imported equipment and expertise;
- production efficiency and construction quality highly dependent on organization and management.

7.1.3 Component supply

All industries producing low-cost motorized vehicles will rely on outside sources of supply of components. However, this aspect of vehicle production is particularly important for small- and medium-scale industries. Sources of supply will include:

- local manufacturers of specialist components;
- importers of components not produced locally, or overseas suppliers of these parts;
- local suppliers of components from scrap motor vehicles.

Thus the reliable and efficient supply of components will be a crucial factor in the success of an efficient vehicle manufacturing enterprise. It is therefore necessary to devote some effort to the selection of component suppliers, and to develop appropriate long-term commercial arrangements with them. The key requirements are:

- capability to supply components promptly, and in adequate quantities, to meet production requirements;
- maintenance of consistent control over the quality of the components;
- competitive prices.

It is desirable to develop mutually beneficial long-term relationships with reliable and reputable suppliers. However, the industry should also seek opportunities to reduce costs by identifying cheaper sources of supply while still maintaining quality.

The vehicle manufacturing industry should have a system for inspecting the quality of bought-in components to ensure that they meet its specification. This is of crucial importance when purchasing renovated components from scrap motor vehicles from an outside supplier. The industry must consider carefully whether such a system of supply is satisfactory, or if quality would be better maintained by 'in-house' renovation of the components.

7.2 PRODUCTION ENGINEERING

The overall aim of any low-cost vehicle manufacturer will be to sell products over a long period of time at a price which will make a profit. This is best achieved by maximizing the quality and effectiveness of the product within the constraints imposed by the price at which they are sold. The design of the product is clearly a key issue in achieving this balance. However, there is also considerable scope for achieving good construction quality and high productivity by the application of efficient production engineering methods. These can have a significant impact on the success of small- and medium-scale industries.

7.2.1 Production tooling

Production tooling is used when a single type of vehicle, or a limited range of standard vehicles, is being manufactured. Production tooling facilitates the efficient manufacture of batches of identical components, and their assembly. It is not suitable for use in an organization making very small quantities of vehicles on a 'one-off' basis.

Production tooling requires capital investment, although in many cases this may consist largely of the time necessary to design and construct it together with a limited allowance for materials. This investment cost must be recovered from the sale of the vehicles so the size of the investment, and hence the amount and complexity of the tooling, will be limited by the production volume over which its cost can be spread.

A wide range of types of production tooling may be used. These include, in approximate order of cost and complexity:

1. Templates: for marking out by hand the shapes and lengths of materials and the position of holes prior to cutting and drilling - used, for example, in making bodywork and frame components.
2. Drilling jigs: for accurately positioning holes which need to be aligned with others for subsequent assembly or in use - employed, for example, to ensure accurate location of suspension components on the frame.
3. Welding fixtures: for accurate positioning, alignment and clamping of components to be joined by welding - used, for example, in the construction of frames, and fabricated axles and wheels.
4. Modifications to general-purpose machines: for rapid production of turned and other machined components. Modifications range from specially shaped cutting tools through to semi-permanent fixtures on the machine - used, for example, in making bearings, hubs and brake components.
5. Small general-purpose press tools: for rapid bending and punching of thin materials on hand-operated machines - used, for example, to make bodywork components, special washers and small brackets.

All these types of production tooling are appropriate to small

and medium-scale manufacturers of low-cost motorized vehicles. In designing production tooling for the manufacture of low-cost vehicles, it is important to ensure that:

- it is simple to make and repair;
- it is simple to use;
- materials can only be located in the correct position;
- dimensional variations of raw materials are allowed for;
- critical points are accurately located.

Accuracy in the construction of production tooling is vital since any error will be repeated on every component produced from the tooling. Robustness and resistance to wear are also essential for long-term use.

It is a pre-requisite for, and indeed the objective of the use of, production tooling that every component made with it is identical. This helps to achieve good product quality by ensuring that a satisfactory design is repeated consistently. Good productivity is achieved by reducing the time required for manufacturing operations, and by reducing wastage and avoiding the need for time-consuming 'fitting' operations during assembly. It also ensures that spares and replacement parts can be fitted without problems to vehicles produced from the tooling.

A further benefit of production tooling is that it enables a skilled operator to produce to a higher standard, and enables many jobs to be carried out by less skilled people than would otherwise be necessary. In general, the more elaborate and costly the tooling, the less skill is required to use it. This effect of the use of production tooling is often referred to as 'de-skilling', but it is more accurately described as 'skill enhancement'. For example, in welded assemblies the strength and appearance of the weld itself is significantly affected by the size of gap between the materials being joined, and the dimensional accuracy of the assembly is affected by distortion caused by the welding process. By using a welding fixture, the materials can be accurately positioned, which controls the gap size, and clamped to prevent distortion. Considerable skill and time is needed to achieve the same weld quality and accuracy by hand.

7.2.2 Quality control procedures

Quality control procedures are important to ensure overall product quality and to minimize the number of rejected components and the time wasted in correcting faults. In many cases, visual inspections and dimensional checks by measurement are all that is required. The production tooling itself can often be designed to provide quality control checks automatically, e.g. by preventing faulty components from fitting into jigs and fixtures, or by dimensions being compared with a template. Special gauges may be used to check that critical dimensions of components such as bearings, which must fit closely on to axles and into hubs, are within specified tolerances. The production workers themselves should carry out the quality control checks as far as possible so that errors may be corrected quickly before repetition, and to encourage individual responsibility for quality standards. However, it is usually desirable for supervisory staff to complement these with sample checks.

It is also useful to carry out quality control checks of

components and materials which are bought in. There can be substantial differences between specified and actual sizes of raw materials, and if a particular item is not available suppliers may send the nearest equivalent without informing the manufacturer.

It is also desirable that all completed vehicles should be carefully inspected, and subjected to a short road test, to confirm that all systems are operating satisfactorily, prior to despatch to the purchaser. The staff responsible for final inspection and testing should be provided with a check-list of all items to be inspected and tested.

7.3 PRODUCTION ORGANIZATION AND MANAGEMENT

The overall efficiency and cost of production is affected not just by the engineering of the production process, but also by its organization and management. In particular:

- in medium or large-scale production, variations to the standard design will involve extra work and expense. The need to charge the customer the full additional cost of this should be balanced against the desirability of offering a range of options to suit particular requirements;
- in batch production, groups of components which are made from the same material, or require similar types of machining, can be made at the same time, to reduce machine set-up times;
- the allocation of tasks can be planned in advance to spread them evenly between the workforce to reduce idle time;
- ordering procedures should aim to minimize material stocks and the capital tied up in them. This is easy when suppliers can be relied upon to deliver quickly. Where suppliers are less reliable, the savings from maintaining low stock levels must be balanced against the possible delays in production caused by lack of materials at the right time;
- in batch production, more efficient use is made of storage and working space, and capital, by making small batches regularly rather than large batches infrequently. This must be balanced against the time lost in setting up machines and tooling for different operations and the administrative costs of frequent ordering.

7.3.1 Production costs

In order to set up and operate a successful vehicle manufacturing industry, it is important to be able to make accurate estimates of the costs of production. Because of the wide variation in production methods and types of vehicle which can be made, in addition to wide variations in costs in different countries, there is little to be gained by quoting indicative costs for one particular set of circumstances. However, either in planning a new vehicle manufacturing business, or for an existing enterprise, accurate estimates of production costs are important:

- (i) to ensure that selling prices are set so that each product brings an income to the enterprise that reflects its costs;

- (ii) to identify opportunities for reducing the cost of manufacturing the product.

7.3.2 Selling price

The selling price of the vehicle will be of overriding importance in determining whether it will be purchased by customers. Thus pricing is important in determining the size of the market.

The key to a successful vehicle manufacturing enterprise is to produce to a specification and at a price which generates a satisfactory level of demand, while providing an acceptable profit margin over the production costs. A commercial company will normally be able to define the minimum level of profit that is acceptable. This minimum acceptable profit will be based on either the desired return on the investment or on a minimum level of income that is required.

In simple terms, the selling price of a vehicle is calculated by adding the desired profit margin to the production cost, and then adding any taxation and distribution or delivery charges that have to be recovered. However, there are other factors which may influence the selling price that is set:

- (i) in some countries it may be necessary to include an allowance in the standard selling price for bargaining with the customer;
- (ii) if the manufacturer sells through agents or retailers, rather than direct to customers, then his pricing policy must not only provide him with an adequate profit while offering the vehicle to the customer at an acceptable price, but also allow the agent to make a reasonable return too. When marketing through an agent the manufacturer may offer an incentive to increase sales, for example by giving a reduction in unit price to the agent for increased quantities sold;
- (iii) if a manufacturer adds vehicles to an existing range of products, and thereby uses his resources more efficiently, he may be able to sell the vehicles at a lower profit margin because some of the overhead costs are already being fully recovered from the other products.

8.1 INTRODUCTION

This chapter provides information on selected low-cost motor vehicles which are commercially produced in different countries and whose acquisition requires some form of collaboration with the source of the technology, for example:

- direct import of complete vehicles;
- import in knocked-down form for local assembly;
- technology transfer agreement for local manufacture.

Information is also provided on sources of key components for low-cost vehicles.

The compendium is not comprehensive but includes selected manufacturers whose products are considered to be relevant to developing country use, and who supplied sufficient information for a detailed entry to be prepared. Inclusion of a manufacturer's products does not, however, imply endorsement by the ILO or the UNCHS.

Each entry includes:

1. Manufacturer's contact address.
2. Illustration of the vehicle(s).
3. A brief description of the product.
4. The methods by which the manufacturer is prepared to make the technology available.
5. Detailed technical description of each vehicle and its performance.
6. Prices.

Since manufacturers have provided information in different forms, price data are presented as follows:

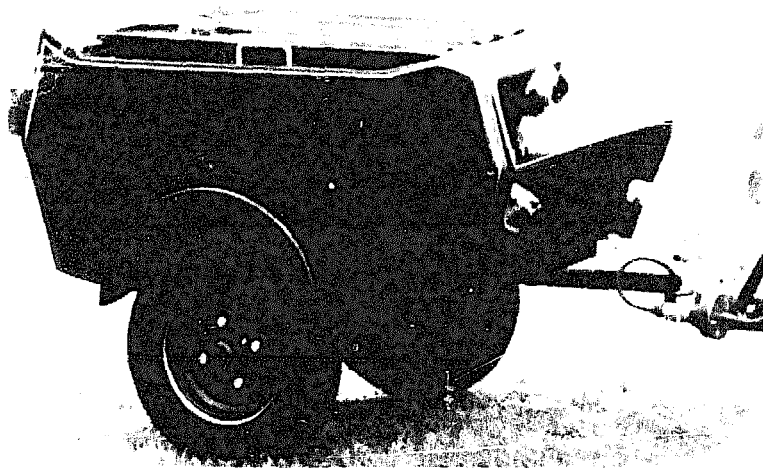
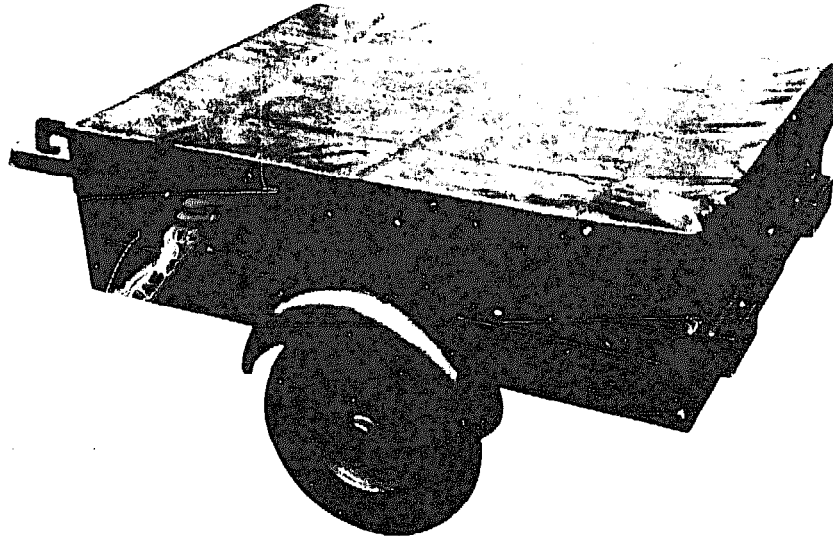
- (i) in the currency, and on the terms (e.g. ex-works, FOB, etc.) quoted by the manufacturer;
- (ii) converted to United States dollars (\$) at the official exchange rate prevailing at the beginning of March 1988.

1. MOTOR CYCLE TRAILERS - FREEWHEEL (UK) LTD

Manufacturer's

address:

Freewheel UK Limited,
Cromer High Station,
Upper Norwich Road,
Cromer,
Norfolk, NR27 0HF,
United Kingdom,
Telephone: (0263) 511210



Description Freewheel UK Limited produce three types of motor cycle trailer, two of which have bodies made from glass-reinforced plastic (GRP), the other having wooden bodywork. The trailers are considered suitable for almost any type of motor cycle and the design can be adapted to customer specification.

Availability of technology There has been very little export to date. However, the manufacturer is prepared to export complete trailers, or rolling chassis and individual parts thereof. It is also willing to supply, on commercial terms, the necessary technology to enable people within developing countries to construct their own trailers and supply only those parts or materials not locally available.

Overall specification

Chassis construction: T-frame made from hollow section steel.

Suspension: Independent rubber-sprung trailing arms.

Wheels: Pressed steel fitted with 4.00 x 8in radial tyres.

Hubs: Double taper roller bearing type.

Hitch: 50mm ball and coupling (does not allow 360° rotational capacity about longitudinal axis).

Brakes: None.

Bodywork

'Tradesman' trailer: Open-top wooden sided box featuring plywood platform.

'Shuttle' trailer: Glass reinforced plastic (GRP) body with lockable lid.

'Pullman' trailer: Larger version of shuttle trailer.

Chassis also available without bodywork.

Dimensions

'Tradesman' trailer: Overall length: N/A
Overall width: N/A
Unladen weight: 36kg

'Shuttle' trailer: Overall length: 1,220mm
Overall width: 740mm
Unladen weight: 30kg

'Pullman' trailer: Overall length: 1,650mm
Overall width: 940mm
Unladen weight: 39kg

Dimensions of load container:

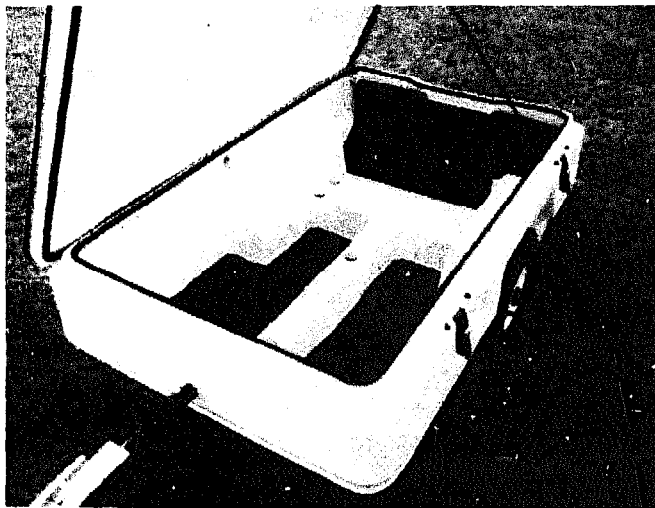
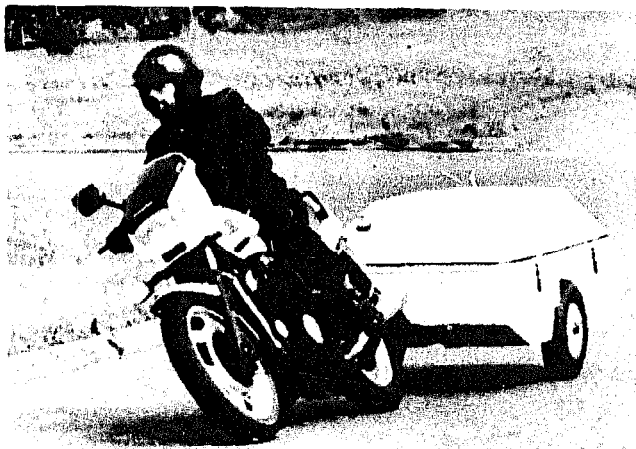
'Tradesman' trailer: Length: 920mm
Width: 710mm
Depth: 310mm

	'Shuttle' trailer:	Length: 900mm Width: 655mm Depth: 350mm minimum to 410mm maximum.
	'Pullman' trailer:	Length: 1,320mm Width: 840mm Depth: 510mm.
Equipment	Standard:	Two rear lights (6 or 12 volt) Stop lights Turn indicators Rear reflectors Socket Towing socket with safety lock Mudguards.
	Optional:	Motor cycle hitch bracket including 50mm ball hitch (various types of bracket available) Motor cycle wiring loom Plastic cover for wooden load container.
Vehicle performance	'Tradesman' trailer:	Maximum payload 180kg (approx)
	'Shuttle' trailer:	Maximum payload 140kg (approx)
	'Pullman' trailer:	Maximum payload 180kg (approx).
Selling price		British retail prices including packing, ex-works:
	'Tradesman' trailer:	£195 (\$355)
	'Shuttle' trailer:	£239 (\$435)
	'Pullman' trailer:	£295 (\$536)
	Small chassis unit (no body or lights):	£159 (\$289)
	Large chassis unit:	£169 (\$307)

2. MOTOR CYCLE TRAILER - SQUIRE

**Manufacturer's
address:**

Squire Sidecars,
Bidavon Industrial Estate,
Bidford-on-Avon,
Warwickshire, B50 4JN,
United Kingdom.
Telephone: (0789) 772690 or
778433



Description Squire Sidecars produce a large motor cycle trailer with a glass-reinforced plastic (GRP) body. It is understood that a smaller version will be produced in the near future.

Availability of technology The company is prepared to export complete trailers or rolling chassis and individual parts thereof.

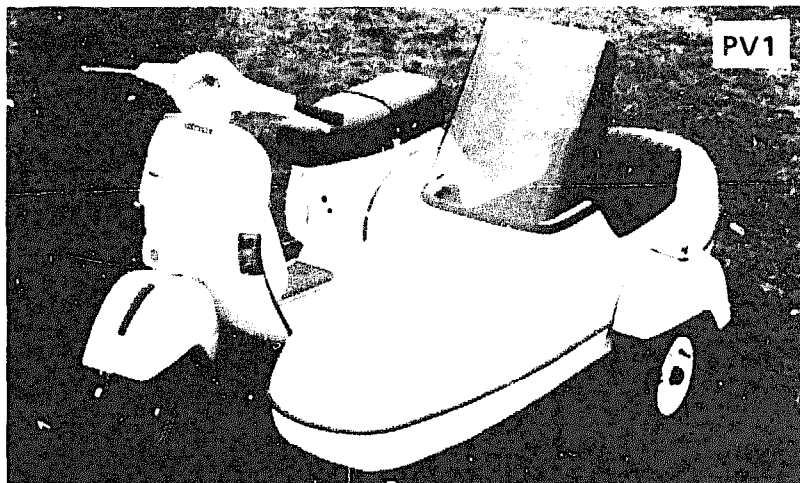
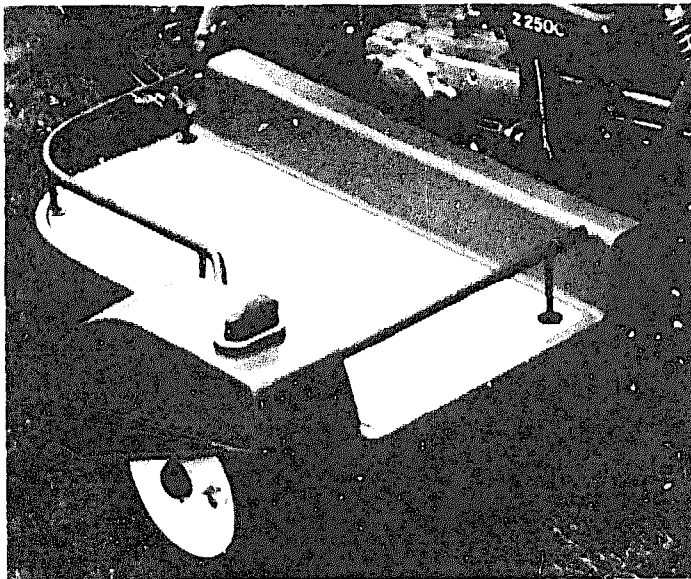
Overall specification	<p>Chassis construction: T-frame made from hollow section steel.</p> <p>Suspension: Independent rubber sprung trailing arms.</p> <p>Wheels: Pressed steel fitted with 4.00 x 8in radial tyres.</p> <p>Hubs: Double taper roller bearing type.</p> <p>Hitch: 50mm ball and coupling. Full 360° rotational capacity about longitudinal axis.</p> <p>Brakes: None.</p>
Bodywork	<p>Glass-reinforced plastic (GRP) body with lockable lid.</p> <p>Chassis also available without bodywork.</p>
Dimensions	<p>'Squire' trailer:</p> <p>Overall length: 1,450mm</p> <p>Overall width: 940mm</p> <p>Unladen weight: 53kg.</p>
Equipment	<p>Standard: Two rear lights (6 or 12 volt) Stop lights Turn indicators Rear reflectors Towing socket with safety lock.</p> <p>Optional: Motor cycle hitch bracket including 50mm ball hitch (various types of bracket available) Motor cycle wiring loom Hitch lock Spare wheel and tyre.</p>
Vehicle performance	<p>Payload: Maximum 250kg (approx.)</p> <p>Interior capacity of load container: 510 litres.</p>
Selling Price	<p>Export price ex-works:</p> <p>Complete trailer: £300 (\$546) (approx.)</p> <p>Chassis unit (no body or lights): £ 90 (\$164)</p>

3. MOTOR CYCLE SIDECAR - SQUIRE

**Manufacturer's
address:**

Squire Sidecars,
Bidavon Industrial Estate,
Bidford-on-Avon,
Warwickshire, B50 4JN,
United Kingdom.
Telephone: (0789) 772690 or
778433

Model CL2



Model PV1

Description Squire Sidecars produce a range of different sidecars mainly designed for the European market. Probably the most suitable models for use in developing countries are the CL2 Loadmaster, recommended for use with small to medium motor cycles, and the PV1 sidecar designed for use with Vespa or Lambretta scooters. Both these models can be supplied with different types of bodywork made of glass-reinforced plastic (GRP), for passenger or load carrying.

Availability of technology The company is prepared to export complete sidecars or rolling chassis and individual parts thereof. It is also willing to supply, on commercial terms, the necessary technology to enable people within developing countries to construct their own sidecars and supply only those parts or materials not locally available. The manufacturing rights for the PV1 Vespa sidecar model have been agreed with an Indian company and this includes all production jigs and fixtures, drawings and technical knowledge.

Overall specification

Chassis

construction: CL2 model - platform type, fabrication in 38mm diameter, 3.2mm thick tubular steel.

PV1 model - platform type, platform type, fabrication in tubular steel with 62.5mm diameter, 3.2mm thick main member.

Suspension: Leading link unit.

Wheel: Pressed steel fitted with 4.00 X 8in tubeless crossply tyre.

Hub: Double ball bearing sealed hub.

Attachment to motor cycle:

CL2 - four arm system using brackets to motor cycle frame. Lower attachment arms are 32mm diameter, 4mm thick steel tube and upper arms are 16mm solid bar, all adjustable for length.

PV1 - bolts to underside of Vespa chassis.

Brakes: None

Bodywork

Model CL2: Options include single seat passenger carrier (ML1), load-carrying box (CL1) and load-carrying platform (CL2).

Model PV1 Options include single seat passenger carrier (PV1) and load-carrying box (CV1).

Chassis also available without bodywork.

Dimensions

CL2 platform carrier:

Overall length: 890mm

Overall width: 710mm

Unladen weight: 40kg.

ML1 single
seater: Overall length: 1,930mm
Overall width: 680mm
Unladen weight: 54.4kg.

CL1 box: Overall length: 1,680mm
Overall width: 680mm
Unladen weight: 54.4kg.

PV1 Vespa
scooter single
seater: Overall length: 1,930mm
Overall width: 680mm
Unladen weight: 38.6kg.

CV1 Vespa
scooter box: Overall length: 1,680mm
Overall width: 680mm
Unladen weight: 38.6kg.

Equipment

CL2: Rear light
Turn indicator
Side light.

ML1, PV1: Rear light
Turn indicator
Side light
Upholstered seat
Windscreen
Luggage compartment
Hood.

CL1, CV1: Rear light
Turn indicator
Side light
Lockable lid.

Vehicle performance

Payload: Maximum all models - 91kg.

Capacity: CV1 - 340 litres
CV1 - 453 litres.

Selling price

British retail prices, ex-works:

CL2 platform
carrier: £333 (\$606)

ML1 single
seater: £488 (\$887)

CL1 box: £497 (\$904)

PV1 (Vespa): £458 (\$833)

PV1
(Lambretta): £494 (\$898)

CV1 (Vespa): £490 (\$891)

CV1
(Lambretta): £509 (\$926)

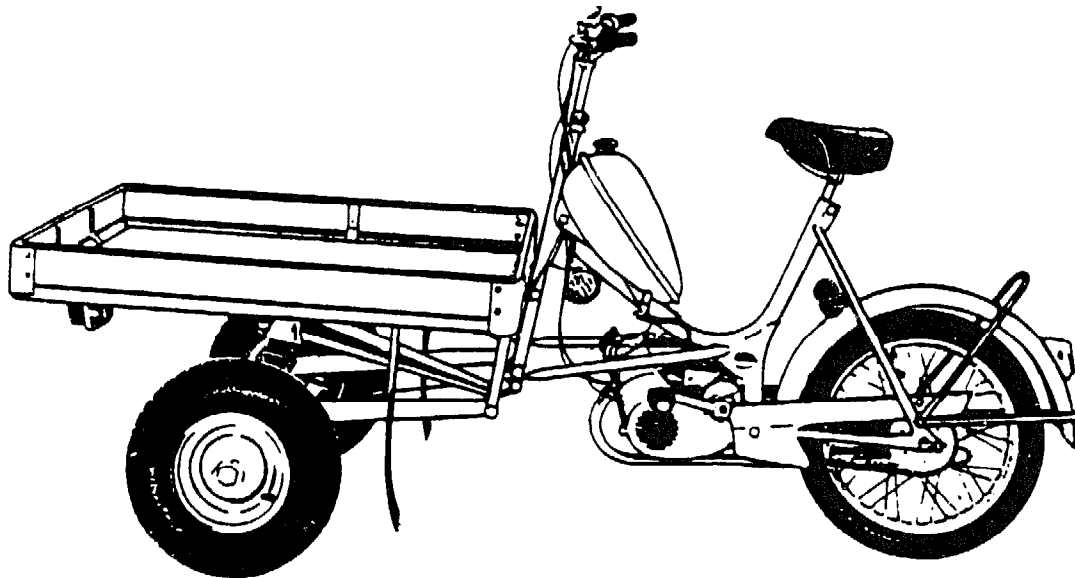
4. PETROL-ENGINEED THREE-WHEELED VEHICLE - MONARK-CRESCENT AB

Manufacturer's

address:

Monark-Crescent AB,
Box 503,
S-43201 Varberg 1,
Sweden.

Telephone: (0340) - 86000



Description Monark-Crescent AB produce a moped-based three-wheeled vehicle with a front-mounted load-carrying platform. The annual production is approximately 5,000 units and the vehicles are used in Sweden by both government bodies and private companies, as well as individual owners.

Availability of technology Monark-Crescent AB were unable to export their vehicles when these details were obtained but hoped to be able to do so by the end of 1987. In the past, 24 units have been shipped to Mozambique together with a stock of spare parts.

Overall specification

Engine	Type:	Single-cylinder two-stroke using petrol/oil mixture.	
	Capacity:	47cm ³ .	
	Method of cooling:	Forced air.	
	Starter:	Pedals.	
Transmission	System:	Clutch and gearbox integral with engine. Final drive chain to single rear wheel.	
	Clutch:	Friction plates, wet type. Hand operated.	
	Number of gears:	Four forward speeds, one reverse. Hand operated.	
Chassis and suspension	Chassis construction:	Tubular steel welded chassis.	
	Front suspension:	Beam axle configuration using two leading links and rubber block springs.	
	Rear suspension:	None (sprung saddle).	
	Steering system:	Handlebar operating a link and pivot system to control the movement of the two front hubs.	
	Wheels:	Front wheels of pressed steel fitted with 4.00 x 8in tyres. Rear wheel of tensioned spoke construction fitted with a 2.50 x 20in tyre.	
	Brakes	Front brake:	Foot pedal controlled, mechanically operated drum brakes.
		Rear brake:	Hand lever controlled, mechanically operated drum brake.
Electrical system	Type:	6 volt flywheel magneto.	
	Equipment:	Head light Rear light Horn	

		Stop light.
Bodywork	Options:	Two sizes of wooden load platform Load-restraining bars Load-carrying wooden box (for small-size platform only).
Dimensions	Small load platform (Model 1189):	Overall length: 2,100mm Overall width: 960mm Unladen weight: N/A.
	Large load platform (Model 1199):	Overall length: 2,500mm Overall width: 1,010mm Unladen weight: N/A.
	Load container floor size:	
	Small load platform:	920mm x 920mm
	Large load platform:	1,320mm x 980mm.
Equipment	Standard:	Front mudguards Tool kit Ignition switch Steering lock.
Vehicle performance	Maximum payload:	150kg.
	Maximum operating speed:	N/A.
	Fuel consumption:	N/A.
Selling price	Export price, ex-works:	
	With small load platform:	7,784 SEK (\$1,307).
	With large load platform:	8,240 SEK (\$1,384).

5. PETROL-ENGINEED THREE-WHEELED VEHICLE - BAJAJ AUTO LTD

Manufacturer's
address:

Bajaj Auto Limited,
Registered Office and Plant,
Akurdi,
Pune - 411 035,
India.
Telex: 0146-263



Description Bajaj Auto produce a range of load-carrying three-wheelers derived from the motor scooter that they also manufacture. The three-wheelers are well proven and are used in large numbers in India. The most popular model is the Autorickshaw which is much used for passenger conveyance.

Availability of technology Bajaj vehicles have been exported to countries in Asia and Africa. They are available by direct export or in completely knocked-down condition (CKD) for local assembly and painting. Bare chassis can also be supplied.

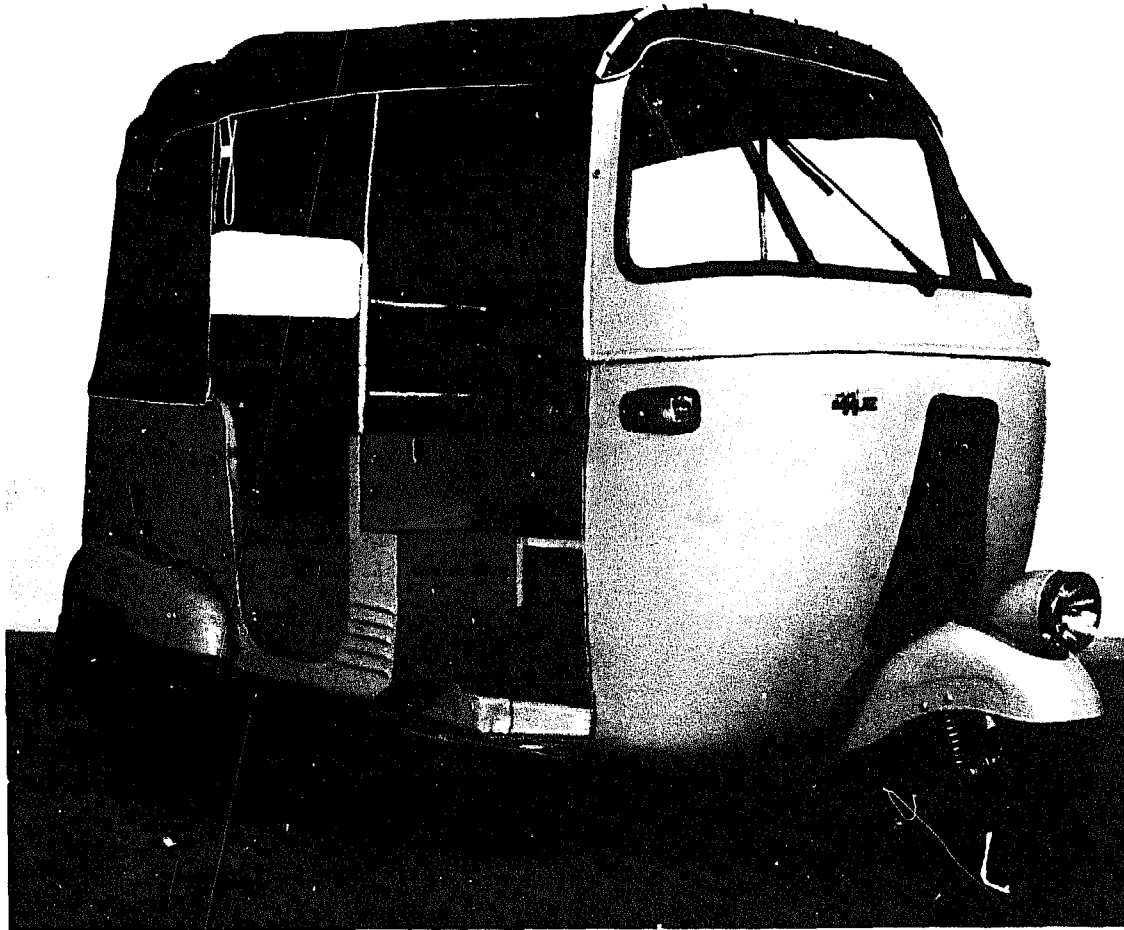
Bajaj are open to discussions on technical collaboration agreements for local manufacture. Technical assistance has been provided for such operations in Indonesia, Taiwan and Bangladesh.

Overall specification

Engine	Type:	Single-cylinder two-stroke using petrol/oil mixture.
	Capacity:	145.45cm ³ .
	Maximum power:	4.1kW.
	Method of cooling:	Forced air.
	Starter:	Hand lever.
Transmission	System:	Clutch and gearbox assembly integral with engine. A differential unit drives two independent final drive chains to the two rear wheels.
	Clutch:	Friction plates, wet type. Hand operated.
	Number of gears:	Four forward speeds and one reverse. Hand operated.
Chassis and suspension	Chassis construction:	Fabricated from pressed steel sections, welded together.
	Front suspension:	Single trailing link featuring coil spring and telescopic damper.
	Rear suspension:	Independent trailing arms of cast aluminium alloy. Torsion bar springs and friction dampers.
	Wheels:	Two-piece, pressed steel construction fitted with 4.00 x 8in tyres.
	Steering system:	Handlebar.
Brakes	Front brake:	Hand-controlled mechanically operated drum brake.
	Rear brake:	Foot pedal controlled, hydraulically operated drum brakes. Hand-operated parking brake.

Electrical system	Type: 6 volt flywheel magneto. Equipment: Head light Rear light Horn Stop light Indicators (Autorickshaw only).
Bodywork	Options: Autorickshaw Pick-up van Delivery van Auto trailer (All of pressed steel construction).
Dimensions	Wheelbase: 1,650mm Track: 1,075mm Unladen Weight: Autorickshaw: 270kg Pick-up van: 260kg Delivery van: 290kg Auto trailer: 415kg. Load container floor size: Pick-up van: 950mm x 1,200mm Delivery van: 1,110mm x 1,300mm Auto trailer: 1,320mm x 4,165mm.
Equipment	Standard: Steering lock Electric windscreen wipers Ignition switch Tool box lock Seats are upholstered with foam rubber and vinyl-coated fabric.
Vehicle Performance	Maximum Payload: Autorickshaw: 3 passengers or 240kg Pick-up van: 510kg Delivery van: 480kg Auto trailer: 715kg. Maximum operating speed: 55km/h (approx). Fuel consumption: 24km/1 (approx) (15km/1 for Auto Trailer).
Selling Price	FOB Bombay: Autorickshaw: Rs 15,712 (\$1,190) Pick-up van: Rs 15,712 (\$1,190) Delivery van: Rs 18,842 (\$1,427).

Rear-engined rickshaw



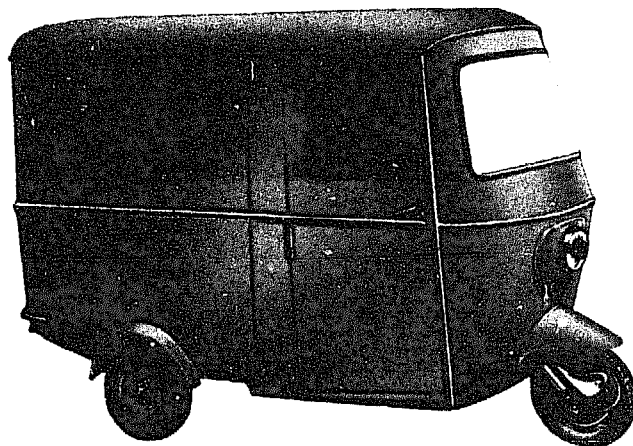
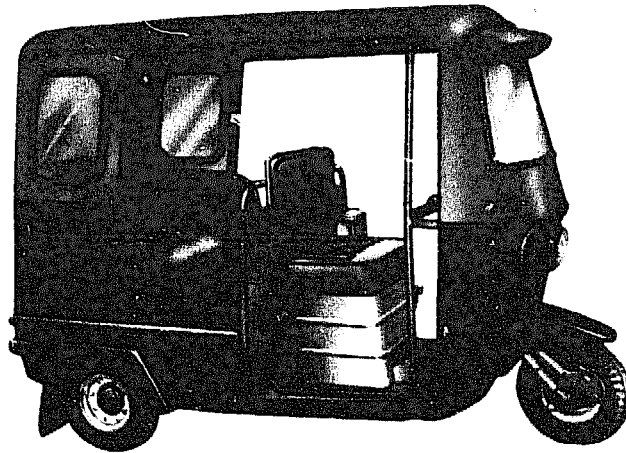
Description Bajaj Auto have recently started production of a slightly larger version of the standard Autorickshaw known as the Rear Engine Autorickshaw with the following differences in overall specification.

Engine:	Positioned underneath passenger compartment between rear wheels.
Transmission:	Final drive to rear wheels is by propeller shafts.
Rear suspension:	Independent trailing arms with coil springs and co-axial hydraulic dampers.
Electrical equipment:	Features a 6 volt battery.
Dimensions:	Wheelbase: 2,000mm Track: 1,150mm Unladen weight: 300kg.
Selling price:	FOB Bombay: Rs 17,310 (\$1,312).

6. PETROL-ENGINEED THREE-WHEELED VEHICLE - AUTOMOBILE PRODUCTS OF INDIA LTD

**Manufacturer's
address:**

Automobile Products of India
(API) Limited,
Lal Bahadur Shastri Marg,
Post Bag No 7320,
Bhandup,
Bombay 400 078,
India.
Telex: 011-71378 APIB



Description API manufacture a three-wheeler chassis which is fitted with a wide variety of different bodywork options. About 15,000 vehicles per year are produced and API have exported to Sri Lanka, Bangladesh and Indonesia.

Availability of technology Available by direct export or in completely knocked-down condition (CKD) for local assembly and painting. Bare chassis can also be supplied.

Overall Specification

Engine	Type:	Single-cylinder two-stroke using petrol/oil mixture.
	Capacity:	175cm ³ .
	Maximum power:	5.2kW.
	Method of cooling:	Forced air.
	Starter:	Kick-start pedal.
Transmission	System:	From gearbox to rear axle through propeller shaft with rubber couplings on either end.
	Clutch:	Friction plate.
	Number of gears:	Four forward speeds and one reverse speed.
Chassis and suspension	Chassis construction:	Tubular steel welded chassis.
	Front suspension:	Trailing links with coil springs.
	Rear suspension:	Beam axle configuration using two longitudinally mounted leaf springs.
	Wheels:	Two-piece pressed steel construction fitted with 4.00 x 8in tyres.
	Steering system:	Handlebar.
Brakes	Front brake:	Hand lever controlled mechanically operated drum brake.
	Rear brake:	Foot pedal controlled, hydraulically operated drum brakes. Hand-operated parking brake.
Electrical system	Type:	6 volt flywheel magneto.
	Equipment:	Headlight Parking/side lights Horn Stop light.
Bodywork	Options:	Autorickshaw

Pick-up van (no doors)
Delivery van
Garbage collection van
Milk/water tanker
Mini-car
Bare chassis.

Dimensions

Chassis: Overall length: 2,650mm
Overall width: 1,250mm
Unladen weight: 212kg.

Equipment

Standard: Spare wheel
Hand-operated windscreen wiper
Tool kit
Speedometer.

Vehicle performance

Maximum payload: 588kg (including weight of body-work)

Maximum operating speed: 62km/h (approx)

Fuel consumption: 26km/l (approx).

Selling price

FOB Bombay:

Fully assembled:

Chassis (inc. half driver's

cab): Rs 14,051 (\$1,065)

Autorickshaw: Rs 18,152 (\$1,375)

Pick-up van: Rs 20,120 (\$1,525)

Delivery van: Rs 23,140 (\$1,753)

Garbage

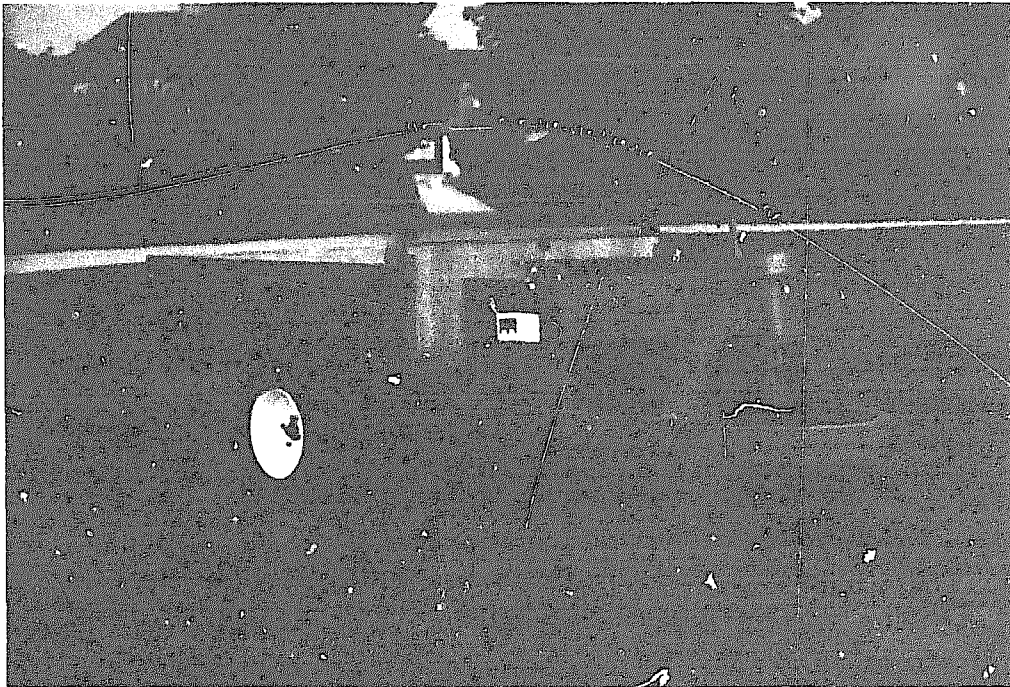
collection van: Rs 21,630 (\$1,639).

7. DIESEL-ENGINEED THREE-WHEELED VEHICLE - MARTIN TRUCKS LTD

Manufacturer's

address:

Martin Trucks Limited,
61 Battlefield Road,
Shrewsbury,
Shropshire, SY1 4AD,
United Kingdom.
Telephone: (0743) 240205



Description Martin Trucks Limited produce three-wheeled motorized tipping trucks called the Bonza series, with 1-tonne capacity for off-road general purpose use. The Bonza is available with various body and engine options, including a 500kg payload version.

Over 4,000 vehicles have been produced since 1958 and there have been exports to many countries.

Availability of technology Available by direct export, in kit form for local assembly and through licensing of the technology for local manufacture. Guarantees would be sought against re-export, and to protect designs and production techniques, etc.

Overall Specification

Engine	Options:	Lombardini (Italy) single-cylinder diesel Kohler (USA) K181 or K301 single-cylinder four-stroke using either petrol or kerosene fuel.
	Capacity:	Diesel - N/A Petrol - 305cm ³ or 476cm ³ .
	Maximum power:	Diesel - 5.2kW or 6.0kW. petrol - 6.0kW or 9.0kW.
	Method of cooling:	Forced air.
	Starter:	Diesel engine - electric start only Petrol engine - rope recoil or electric start.
	Transmission system:	Clutch and gearbox assembly independent from engine. Primary drive by roller chain and sprockets. Final drive by propeller shaft to live rear axle featuring a differential unit.
	Clutch:	Friction plate.
	Number of gears:	Three forward speeds, one reverse.
Chassis and suspension	Chassis construction:	Fabricated from 102mm x 51mm x 4mm steel channel section and 12mm steel plate.
	Front suspension:	None.
	Rear suspension:	None.
	Wheels:	Pressed steel, front tyre size 4.00 x 12in, rear tyre size 6.00 x 12in.

	Steering system:	Steering wheel with chain-driven gearing to front forks.
Brakes	Front brake:	None.
	Rear brake:	Foot pedal controlled, hydraulically operated motor car - type drum brakes. Hand-controlled parking brake.
Electrical system		
	Type:	12 volt battery and alternator (optional on petrol engines).
	Equipment:	Electric starter, lighting, horn (optional).
Bodywork		Rearward tipping load container with plywood side and tailboards.
	Options:	Bulk extension carrier. Cab enclosure.
Dimensions		
		Overall length: 3,050mm
		Overall width: 1,270mm
		Overall height: 1,125mm
		Unladen weight: 382-420kg.
Load container size:	One tonne:	1,676mm x 1,245mm x 305mm.
	Half tonne:	1,350mm x 890mm x 305mm.
Vehicle performance		
	Maximum payload:	1 tonne (500kg for model BHH1).
	Maximum operating speed:	29km/h (variation possible by changing sprocket sizes).
	Fuel consumption:	N/A.
Selling price	Export prices on application.	

Home market prices of Bonza 1 tonne tipping trucks:

<u>Petrol Engine:</u>		
recoil start		
6kW	£2,375	(\$4,319)
9kW	£2,479	(\$4,508).
electric start:		
6kW	£2,499	(\$4,544)
9kW	£2,599	(\$4,726).

Diesel Engine

electric start:

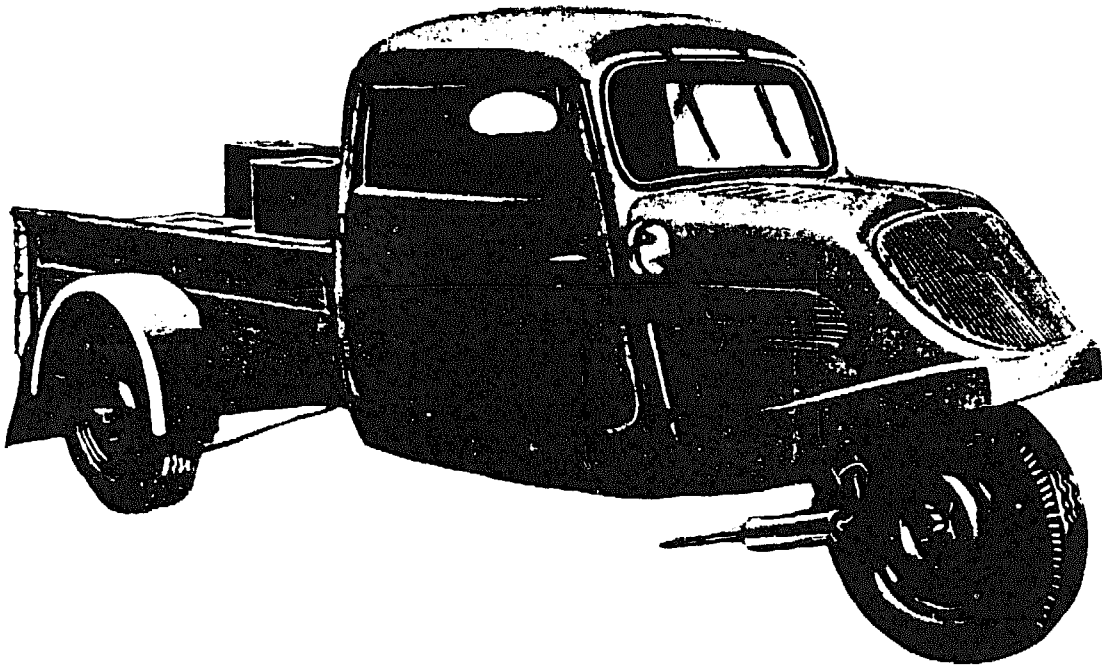
5.2kW	£2,925	(\$5,319)
6.0kW	£3,049	(\$5,545).

8. DIESEL-ENGINEED THREE-WHEELED VEHICLE - BAJAJ TEMPO LTD

Manufacturer's

address:

Bajaj Tempo Limited,
Akurdi,
Pune-411 035,
India.
Telex: 0146-252 TMPO IN



Description Bajaj Tempo produce a motorized three-wheel chassis unit that is fitted with a choice of three main body options - Cart, Pick-up and Autorickshaw:

- the Pick-up is similar to the Cart but has rear suspension and a fully enclosed cab;
- the Autorickshaw is similar to the Pick-up but has an enclosed passenger-carrying unit.

Annual production is about 2,000 vehicles and exports have recently commenced to Bangladesh.

Availability of technology Willing to export. Terms by negotiation.

Overall specification

Engine	Type:	Single-cylinder four-stroke diesel.
	Capacity:	Mechanized Diesel Cart: - 325cm ³ . Pick-up/Autorickshaw: - 454cm ³ .
	Maximum power:	N/A.
	Method of cooling:	Forced air.
	Starter:	Mechanized Diesel Cart - rope starter. Pick-up/Autorickshaw - electric starter.
	Transmission system:	Clutch and gearbox assembly mounted independently from engine. Enclosed duplex chain drive to clutch. Enclosed simplex chain final drive to wheel.
	Clutch:	Friction plate type.
	Number of gears:	Mechanized Diesel Cart - two forward speeds and one reverse. Pick-up/Autorickshaw - four forward speeds and one reverse.
Chassis and suspension	Chassis construction:	Tubular steel welded chassis.
	Front suspension:	Pivoting front sub-assembly using coil springs and hydraulic dampers.
	Rear suspension:	Mechanized Diesel Cart - none. Pick-up/Autorickshaw - independent swing axles with coil springs.
	Wheels:	Pressed steel, fitted with 6.40 x 15in tyres.
	Steering system:	Mechanized Diesel Cart - handlebar. Pick-up/Autorickshaw - geared steering wheel.

Brakes

Front brake: Mechanized Diesel Cart - none
Pick-up/Autorickshaw - foot pedal controlled hydraulically operated system actuating drum brakes on front and rear wheels.

Rear brake: Mechanized Diesel Cart - foot pedal controlled, mechanically operated drum brakes.
Pick-up/Autorickshaw - see under front brake. Hand controlled, mechanically operated parking brake.

Electrical system

Type: Mechanized Diesel Cart - none
Pick-up/Autorickshaw - 12 volt battery and dynamo.

Equipment: Pick-up/
Autorickshaw: Electric starter
Head lights
Rear lights
Stop lights
Horn.

Bodywork

Mechanized Diesel Cart: Steel load container.

Pick-up: Fully enclosed, pressed steel cab and steel load container.

Autorickshaw: Fully enclosed, pressed steel body and cab with provision for passenger seating.

Dimensions

Wheelbase: 3,070mm
Track: 1,430mm
Overall length: 4,270mm
Overall width: Mechanized Diesel Cart - 1,550mm
Autorickshaw - 1,730mm
Unladen weight: Mechanized Diesel Cart - 450kg
Autorickshaw - 750kg.

Load container floor size:

Mechanized Diesel Cart: 1,980mm x 1,235mm.

Pick-up/
Autorickshaw: 1,980mm x 1,235mm.

Vehicle performance

Mechanized Diesel Cart: Maximum payload 1 tonne (approx).

Pick-up/
Autorickshaw: Maximum payload 762kg plus
driver.

Maximum
operating
speed: Mechanized Diesel Cart - 20km/h

Pick-up/
Autorickshaw: 45km/h.

Fuel
consumption: Mechanized Diesel Cart - N/A
Pick-up/Autorickshaw - 25km/l
(approx).

Selling price

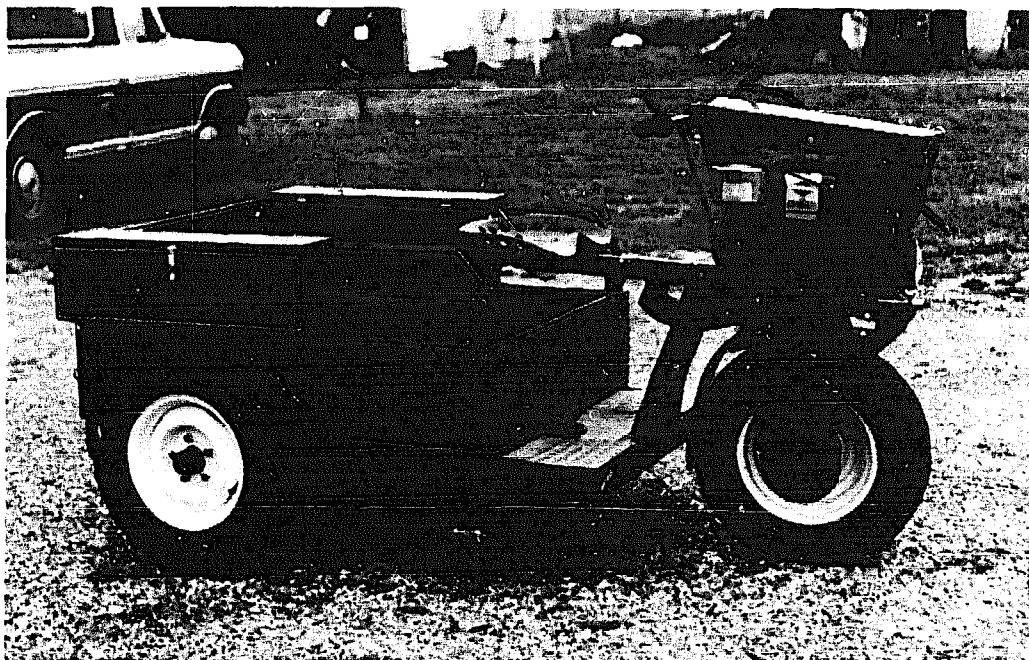
FOB Bombay:

Mechanized
Diesel Cart: Rs 11,241 (\$852)
Pick-up: Rs 30,147 (\$2,284)
Autorickshaw: Rs 30,849 (\$2,337).

9. DIESEL-ENGINEED THREE WHEELED VEHICLE - TRAG

Manufacturer's

address: Trag Project,
P.O. Box 466,
Marshfield,
Missouri 65706,
United States.



Description The Trag is a front-wheel drive, three-wheeled vehicle with the engine located over the front wheel. Its uses include general utility hauling of goods and people. It has been developed for overseas use and local manufacture using basic resources. A two-wheeled version that resembles a motor cycle has also been developed.

Since 1979 approximately 250 Trags have been produced at Marshfield and they have been exported to a number of organizations in developing countries. About 100 Trags have been produced in other countries.

Availability of technology Trag Project is a non-profit organization and Trags are not sold on the retail market. They are usually sent to missionaries or mission projects, or other non-profit organizations, the cost typically being met by sponsorship by groups within the United States.

Trag Project will export a manufacturing package that contains jigs, fixtures, and parts for Trags in various stages of completion, as well as sending someone to assist in setting up production.

Overall specification

Engine	Options:	Lombardini (Italy) 6LD single-cylinder, four-stroke diesel. Briggs and Stratton (USA) single-cylinder, four-stroke petrol.
	Capacity:	N/A.
	Maximum power:	Diesel - 4.5kw or 5.6kw Petrol - 6.0kw or 7.5kw.
	Method of cooling:	Forced air.
	Starter:	Electric or rope start.
	Transmission system:	V-belt drive from engine to intermediate shaft, then chain drive to front wheel.
	Clutch:	V-belt tightened by idler.
	Number of gears:	Three forward speeds.
Chassis and suspension	Chassis construction:	Fabricated from lengths of steel box section.
	Front suspension:	None.
	Rear suspension:	None.
	Wheels:	13in automobile-type wheels.
	Steering system:	Handlebar.
Brakes	Front/rear brake:	Foot pedal controlled, hydraulically operated drum brakes acting on all wheels.
Electrical system	Type:	Optional 12 volt battery and alternator.
	Equipment:	Optional. If desired full automotive equipment can be fitted, i.e.: Electric starter Lights Indicators Horn, etc.

Bodywork

Options: Open box load container
Taxi model with longitudinal seats.
Medical unit fitted with two stretchers and medical supply cabinets.

Dimensions

Overall length: 2,286mm
Overall width: 1,372mm
Wheelbase: 1,524mm
Track: 1,219mm
Unladen weight: 227kg.

Vehicle performance

Maximum payload: 227kg plus driver.

Maximum operating speed: 32-40km/h (depending on drive sprocket ratio).

Fuel consumption: Petrol - 14-23km/l
Diesel - 21-35km/l.

Selling price

These costs are ex-works, fully assembled.

Petrol: all electric and options, for licensed road use, bench seat, auxiliary fuel containers, etc: \$1,950.

Diesel: all electric and options, for licensed road use, bench seat, auxiliary fuel containers, etc. \$2,900.

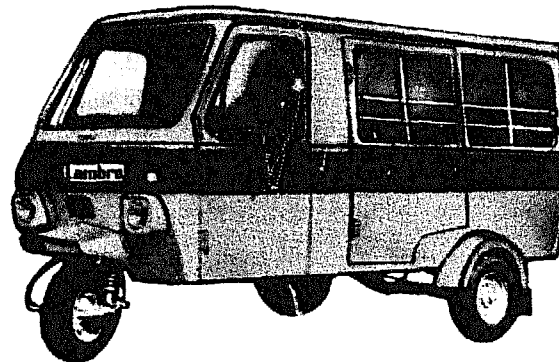
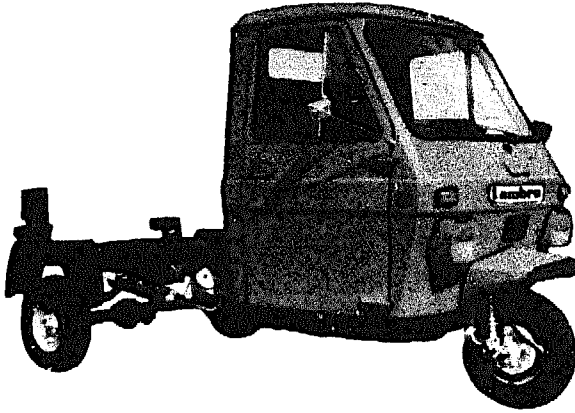
These costs are for the highest specification models, and would be lower for a plain, rope-start, utility model.

Packing cost is \$200 and shipping can be arranged.

10. DIESEL-ENGINEED THREE WHEELED VEHICLE - LAMBRO

Manufacturer's
address:

Scoters India Limited,
Sarojini Nagar,
Lucknow - 226008,
India.



Description The 'Lambro' three-wheeled vehicle is manufactured in India with technological support from an Italian company. The vehicle is available with a number of different bodywork specifications and can be adapted to suit the requirements of individual customers.

Approximately 5,000 vehicles have been produced since 1978. Export to Bangladesh is well established.

Availability of technology Available in semi-knocked down (SKD) form for export. Terms by negotiation.

Overall specification

Engine	Options:	LDA-510 single-cylinder, four-stroke diesel. Single-cylinder, two-stroke, using petrol/oil mix.
	Capacity:	Diesel - 510cm ³ . Petrol - 198cm ³ .
	Maximum power:	Diesel 8.2kW. Petrol 7.1kW.
	Method of cooling:	Forced air.
	Starter:	Electric.
	Transmission system:	Constant mesh gearbox. Propeller shaft featuring flexible couplings drives differential on rear beam axle.
	Clutch:	Friction plate clutch, foot pedal operated. Diesel - dry clutch, single plate. Petrol - wet clutch, multi-plate.
	Number of gears:	Four forward speeds, one reverse.
Chassis and suspension	Chassis construction:	Fabricated from steel tubing and channel section.
	Front suspension:	Front fork with leading links, coil springs and telescopic dampers.
	Rear suspension:	Beam axle supported on leaf springs. Telescopic dampers.
	Wheels:	Pressed steel fitted with 4.50 x 10in tyres.
	Steering system:	Steering wheel using worm and wheel gearing.
Brakes	Front/rear brake:	Foot pedal controlled, hydraulically operated drum brakes on all wheels.

Electrical system	Type: 12 volt battery and dynastarter.
	Equipment: Head light Rear lights Windscreen wiper.
Bodywork	Options for both diesel- and petrol-engined versions include: Auto Rickshaw Saloon Tipping load container Ambulance (petrol engine only) Delivery van Bodywork of pressed steel construction.
Dimensions	Auto Rickshaw (diesel): Overall length: 3,177mm Overall width: 1,480mm Wheelbase: 2,270mm Track: 1,316mm Unladen weight: 490kg. Auto Rickshaw (petrol): Overall length: 3,179mm Overall width: 1,480mm Wheelbase: 2,270mm Track: 1,316mm Unladen weight: 450kg. Load container size: 1,940mm x 1,450mm.
Vehicle performance	Maximum payload: 600kg. Maximum operating speed: Diesel - 65km/h (approx). Petrol - 53km/h (approx). Fuel consumption: Diesel - 33km/l at 30km/h. Petrol - 21km/l at 30km/h.
Selling price	FOB, any Indian port, in chassis form only. Diesel-engined version: Rs30,300 (\$2,296). Petrol-engined version: Rs19,935 (\$1,510).

11. VEHICLE COMPONENTS - INDESPENSION

Manufacturer's

address:

Indespension,
Belmont Road,
Bolton, BL1 7AQ,
United Kingdom.
Telephone: (0204) 58434

Description Indespension specialize in trailer equipment and have supplied components to many countries for local assembly of low-cost vehicles. They are willing to advise on the production of trailers.

Availability of technology All components available by direct export; terms by negotiation.

Product range Product range includes:

Rubber-sprung arm suspension units complete with or without, stub axles. A variety of stub axle specifications are available to suit different types of hubs (see Annex 3 for illustration).

Rubber-sprung arm, load capacity range per pair: 25-1500kg.
British retail prices from £20.50 (\$37) per pair.

Hubs (braked and unbraked), wheels and tyres.

Trailer couplings (50mm ball type), pressed steel and cast iron construction.

British retail prices from £8.90 (\$16).

Wide variety of ancillary equipment for trailers, including complete chassis, electrical components, etc.

Further details of product range and prices on application.

12. VEHICLE COMPONENTS - AVON RUBBER COMPANY LTD

Manufacturer's

address: Avon Rubber Company (Bridgend) Limited,
Engineering Products Division,
Industrial Estate,
Bridgend,
Glamorgan CF31 3RE,
United Kingdom.
Telephone: (0656) 55571

Description Avon supply a range of axles, hubs, wheels and tyres.

Availability of technology Available by direct export; terms by negotiation.

Product range Product range includes:

Non-driven beam axles with integral rubber-sprung arm units and hubs (braked and unbraked).

Axle load capacity range: 550-3,000kg.

Various types of wheels and tyres.

Rubber-sprung arm units complete with, or without, hubs (braked or unbraked).

Load capacity range per pair: 140-1,550kg.

Further details of product range and prices on application.

13. VEHICLE COMPONENTS - AXLES LTD

Manufacturer's

address: Axles Limited
Wiggenhall Road,
Watford,
Herts, WD1 8AR,
United Kingdom,
Telephone: (0923) 25394/6

Description Axles Limited supply a range of axles, hubs, wheels and tyres for low-speed vehicles.

Availability of technology Available by direct export; terms by negotiation.

Product range Product range includes:

Non-driven beam axles with hubs (braked or unbraked).
Axle load capacity range: 600-3,500kg.
British retail prices from £36.65 (\$67).

Leaf springs for beam axles.
British retail prices per pair from £30.70. (\$56).

Rubber-sprung arm units with hubs.
Load capacity range per pair: 600-3,500kg.
British retail prices per pair from £75.60 (\$137).

Various types of wheels and tyres.

Further details of product range and prices on application.

14. VEHICLE AXLES - SALATI

Manufacturer's

address:

Salati Srl,
Via Raffaello 2,
Zona Ind., Mancasole,
I-42100 Reggio Emilia,
Italy.
Telephone: (0522) 43443-7

Description Salati produce axle units which have been exported to countries world-wide, including many developing countries.

Availability of technology Axle units available by direct export; terms by negotiation.

Product range Product range includes:

Non-driven beam axles with a variety of hub specifications to suit different types of wheel from scrap motor vehicles. Available with or without braked hubs and with no suspension mechanism (see Annex 5 for illustration).

Axle track width available to customer's own specification.

Axle load capacity range: 400-8,500kg.

Prices per axle from \$25.

Further details of product range and prices on application.

15. TRAILER EQUIPMENT - BRADLEY DOUBLELOCK

Manufacturer's

address: Bradley Doublelock,
Victoria Works,
Bingley,
West Yorkshire, BD16 2NM,
United Kingdom.
Telephone: (0274) 560414

Description Bradley Doublelock specialize in trailer equipment.

Availability of technology Available by direct export; terms by negotiation.

Product range Product range includes:

Wide variety of trailer couplings (50mm ball type). British retail prices from £8.59 (\$16).

Rubber-sprung arm suspension units with a variety of hub specifications to suit different types of wheels from scrap motor vehicles.

Load capacity range per pair: 275-2,000kg.

Non-driven beam axles featuring integral rubber-sprung arm units and hubs (braked and unbraked).

Ancillary equipment for trailers.

Further details of product range and prices on application.

FRAME MATERIALS AND CONSTRUCTION METHODS

1. Chassis construction

The frame of a vehicle is often referred to as the chassis. A chassis is a structure which connects the parts of the vehicle in their proper spatial relationships and accepts the loads they create. It should be stiff enough to resist too much distortion, which will both adversely affect controllability and over-stress other components, and strong enough to withstand the loads applied to it. However, it should be no heavier than necessary since this will reduce the useful payload of passengers and/or goods that the vehicle can carry.

The chassis of modern motor cars are usually made of pressed steel which is ideally suited to large-scale production for this application. However, it is not appropriate for rugged, low-cost motor vehicles produced in smaller quantities since the capital investment in machinery and production tooling is very high.

For low-cost vehicles produced in relatively small numbers, hollow steel sections are the most suitable materials to use for constructing the chassis. Lugs can be welded to the chassis to facilitate the mounting of bodywork and other components. The preferred dimensions of the steel sections will depend on the chassis design and the intended use of the vehicle, but in many developing countries the design will be constrained by the available choice of steel sections.

Hollow steel sections are rectangular, square or round in cross section. Rectangular and square sections are easier to work with than round sections because the welded joints can be simply formed on flat faces. They also provide flat faces for convenient mounting of additional members, lugs and other components. However, round sections can be bent using a tube-bending machine to form curves, which reduces the number of welded joints required in a chassis. When bending tube of 38mm and over, which will usually be the case for vehicle chassis, a hydraulically operated bending machine is needed. Steel water pipes of around 25mm to 80mm diameter are often available in developing countries and are sometimes used for fabricating chassis.

Angle, channel and I-sections of mild steel are often more readily available than hollow sections in developing countries. Though they are suitable for fabricating main chassis members, these 'open' sections have a lower strength-to-weight ratio than hollow sections. Consequently, the use of open sections usually results in a heavier chassis. Angle section is especially poor at resisting twisting or torsion loads. It should therefore never be used for fabricating a single main chassis member such as used in the T-frame shown in Figure 3.4. in the main text.

As a quick guide, it is worth mentioning that two of the commercially produced vehicles featured in Chapter 8 have the following chassis specifications:

(i) Martin Truck (payload 1 tonne) - chassis fabricated from 102mm x 52mm x 4mm steel channel and 12mm steel plate, all welded construction;

(ii) Lambro (payload 600kg) - central beam of 80mm diameter steel tubing welded to load-carrying platform of steel channel.

Table Al.1 lists the weight, relative cost and relative strength of some of the most common sections used for chassis construction. The theoretical calculation of the most efficient section to use for the main longitudinal members of a chassis can be quite complex. Their required strength depends on such factors as the vehicle dimensions, weight and distribution of load, and dynamic forces experienced when driving, braking, traversing rough ground, etc. It is advisable to seek advice from an experienced engineer to calculate the preferred material dimensions for a chassis, and crucially important that a prototype chassis should be thoroughly tested under realistic operating conditions before embarking upon commercial manufacture and sale.

TABLE Al.1: Characteristics of common steel sections

Section	Size (mm)	Weight (kg/m)	Relative cost per unit length	Relative strength in pure bending (z value cm ³)
Equal angle	25 x 25 x 3	1.11	33	0.45
	30 x 30 x 3	1.36	39	0.65
	40 x 40 x 3	1.83	48	0.92
	50 x 50 x 5	3.77	89	3.05
	50 x 50 x 6	4.47	105	3.61
Unequal angle	50 x 40 x 5	3.37	89	2.95
	65 x 50 x 5	4.35	120	5.14
	75 x 50 x 6	5.65	146	8.01
Channel	76 x 38 (3" x 1.5")	6.86	160	20.00
	102 x 51 (4" x 2")	10.57	236	41.46
Hollow section	25 x 25 x 3.2	2.16	63	1.75
	30 x 30 x 3.2	2.65	83	2.67
	40 x 40 x 2.6	3.03	86	4.47
	40 x 40 x 4.0	4.46	137	6.07
	50 x 50 x 3.2	4.66	138	8.62
	50 x 30 x 2.6	3.03	87	4.96

Source: Indespension

2. Bodywork support and axle

On most vehicle designs the bodywork or load container is supported on the outer frame of the chassis. This outer frame is usually made from angle section steel. A full-width axle of a vehicle is best made from hollow section steel. Table Al.2 gives recommended steel section dimensions for the outer frame and axle for different payload capacities.

TABLE A1.2: Recommended steel sections, outer frame and axle

Load container size	Gross weight capacity of axle	Outer frame (angle section)	Non-driven beam (hollow section)
1,250 x 900mm	200kg	40 x 40 x 3mm	50 x 30
1,500 x 900mm	500kg	40 x 40 x 3mm	50 x 50 x 2m
1,750 x 1,250mm	500kg	50 x 50 x 5mm	50 x 50 x 2m
2,000 x 1,250mm	1000kg	50 x 50 x 5mm	63.5 x 63.5 x 4mm

Source: Indespension

3. Welding

Joints in steel structures are usually made by welding. Bolted joints can be used but have to be considerably more complicated to achieve the same strength. Except where parts must be easily detachable, welded construction is preferred. There is much variation in the design of joints for welding. Examples of good steel joints are shown in Figure A1.1. Many joints can be further strengthened by adding gussets. Good-quality welding is essential to achieve maximum joint strength. Electric arc or gas welding can be used but one of the most efficient types of welding for small-scale manufacture is metal inert gas (MIG). A MIG welding plant uses a continuous wire feed for the electrode with a constant supply of inert gas to shield the welding arc. The gas is typically composed of 95% carbon dioxide and 5% argon. This process results in strong, stable welds, and if the gas and wire consumables are locally available, is very economical.

4. Drilling chassis members

When drilling chassis members, it is advisable to position the holes on the neutral axis (NA) of the section whenever possible, so that metal is only removed from areas where the stress is at a minimum. Figure A1.2 indicates the position of the neutral axis for some common steel sections. If a bolt is to pass through both sides of a hollow section, it is important to fit a spacer inside to prevent the section being crushed as the bolt is tightened.

5. Strengthening a chassis

An existing chassis can be strengthened by the welding of additional members at key positions. The sketches shown in Figure A1.3 give some useful ideas on how different hollow and open sections can be strengthened. Generally the additional stiffening members need not run the full length of the main members, but should be positioned to span the weakest point or the most highly stressed part of the main member.

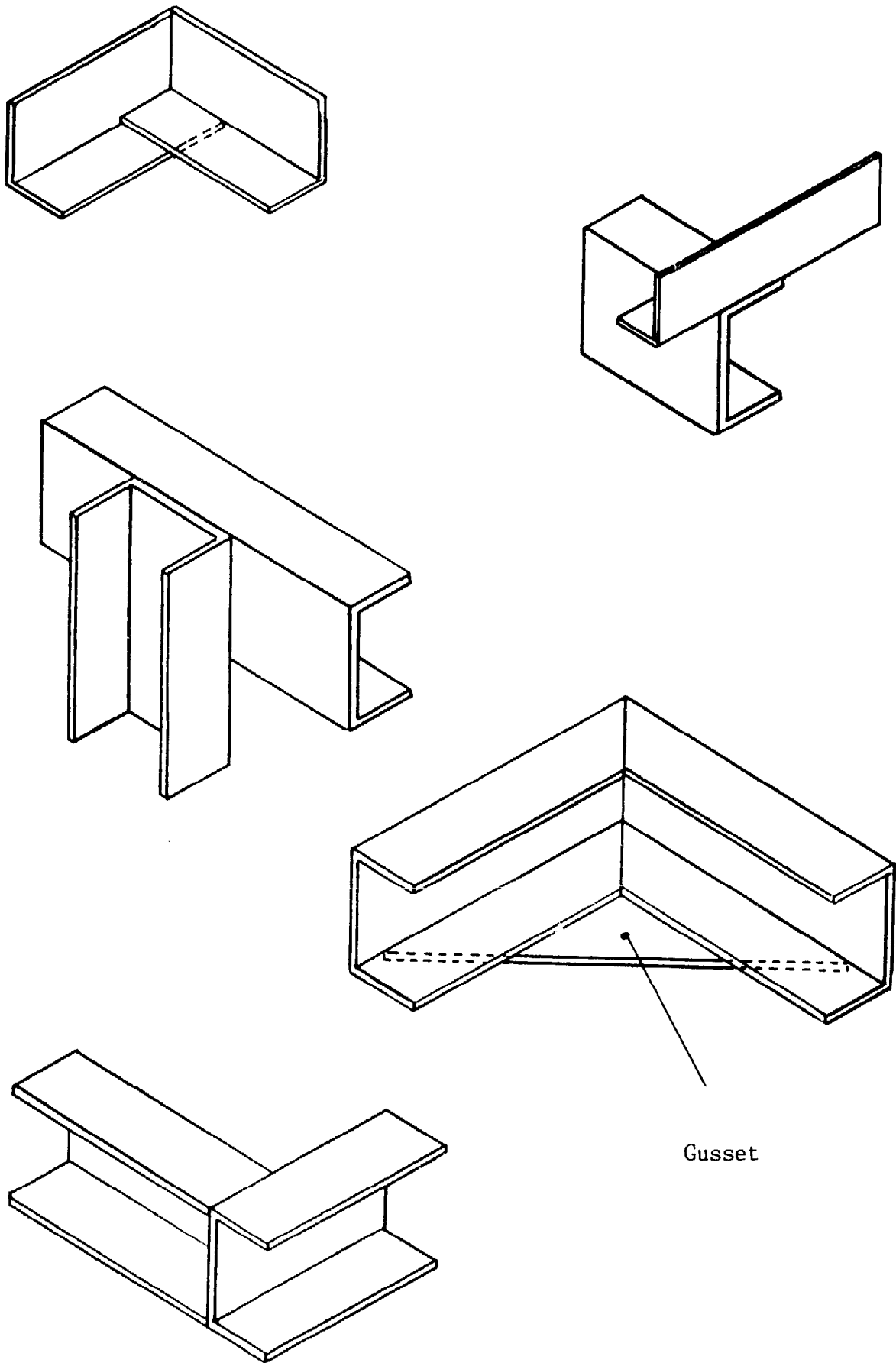


Fig. A1.1 Strong welded joints

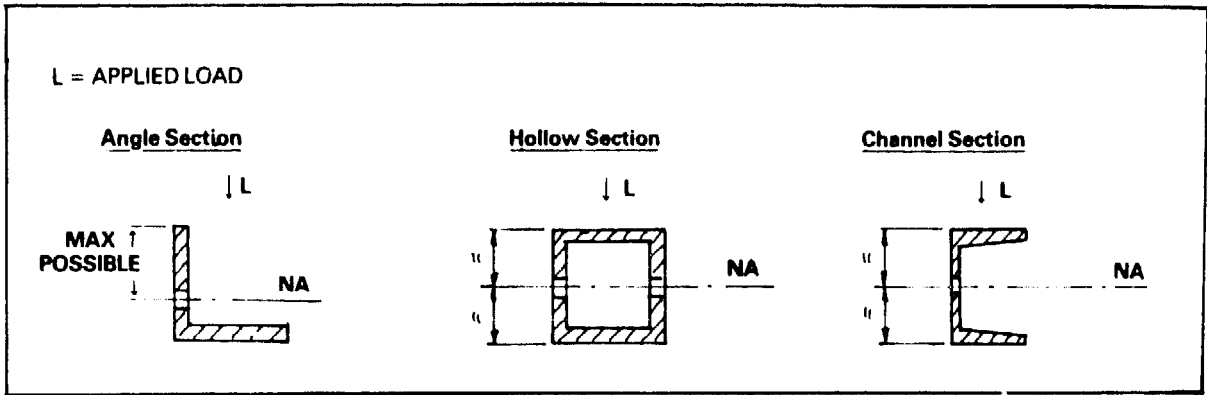


Fig. A1.2 Preferred location of holes in structural steel section

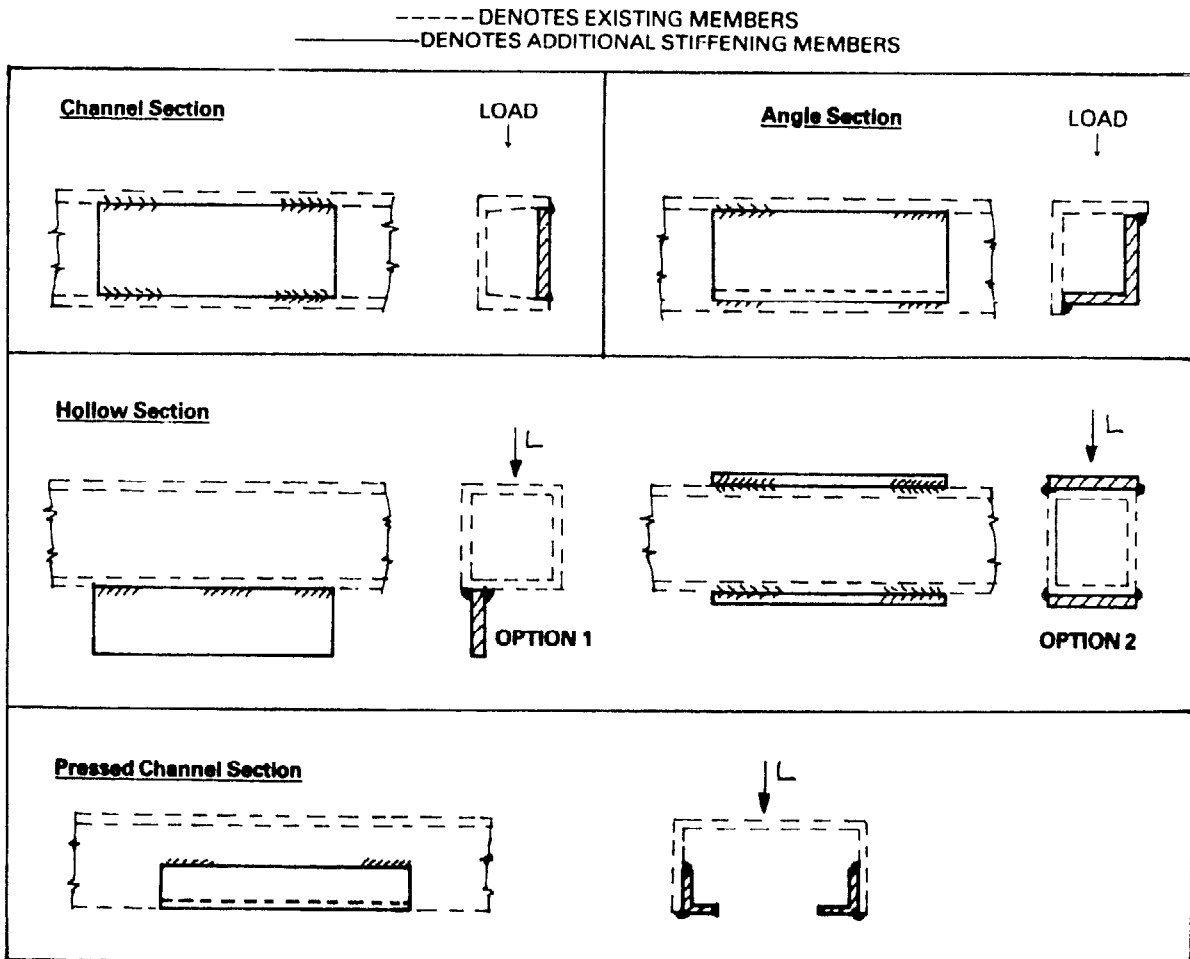


Fig. A1.3 Recommended methods of strengthening chassis members

BODYWORK

1. Introduction

The type of bodywork attached to a low-cost vehicle chassis is determined primarily by its intended use. Many commercial manufacturers offer the same low-cost vehicle chassis but with a number of options for bodywork. The two main categories of bodywork are goods containers and passenger transporters. However, in practice it is often the case that neither type of bodywork is used solely for its intended purpose since it is common for low-cost vehicles to carry combined loads of goods and passengers. Low-cost vehicles can be sold in chassis form with no bodywork, or with only a load-carrying platform, so that the purchaser can arrange the construction of bodywork to suit individual requirements. Irrespective of which type of load-carrying bodywork is fitted, all low-cost motor vehicles have basic bodywork requirements for driver seating and weather protection, etc. Each of these aspects is discussed below.

2. Basic requirements

The basic bodywork requirements for a low-cost motor vehicle are as follows:

1. Driving seats can vary from a small wooden bench to a large fully upholstered seat. A resilient seat will add to the driver's comfort, but more important is the driving position afforded by the seat. The controls must be easily accessible and all-round vision adequate.
2. A fabricated chassis needs a steel or wooden floor pan to support the driver's feet. It is also useful for support when mounting and dismounting from the vehicle and, if made from steel plate, it can offer additional bracing to the front chassis members.
3. A mudguard for the front wheel(s) is an important addition. It protects the driver from mud and stones being flung up. Rear mudguards are also important as they help to protect the vehicle itself, and following vehicles, from road debris.
4. Some vehicles feature weather protection for the driver. In its simplest form this can be no more than an ordinary umbrella clamped to the frame. This offers effective protection from the sun, and light rain. Another option is to have several struts of steel or wood supporting a more permanent canopy - made of waterproof cloth or sheet steel - from which flexible plastic sides can hang down to provide additional protection. The sides can be rolled up and stowed on the roof.
5. A more substantial form of enclosure for the driver consists of rigidly mounted sides, a roof and integral doors and perspex windows. Perspex is easier to mount than glass and less prone to cracking due to vibration. If the vehicle speed is likely to exceed 30km/h a windscreen should be fitted to protect the driver's eyes,

especially if the vehicle is operating in dusty conditions. If the vehicle has a fully enclosed driver's cabin, it is important to fit a windscreen wiper to ensure adequate visibility in the rain.

6. On most motorized vehicles rear view mirrors are an important addition. Their use is especially important on vehicles that operate in dense traffic, and they are essential on any vehicle from which rearward vision is restricted.

7. A fully enclosing cowl can be fitted to give weather protection to the engine and transmission assembly. (See illustration of the Autorickshaw produced by Bajaj Auto Ltd. of India, example 5 in Chapter 8, which has a roof for both the driver and passengers and also a steel cowl enclosing the engine.) It also limits unauthorized access to these parts, which may be an important consideration in an urban environment. However, it is important that this enclosure should not shield the engine from cooling air to the extent that it overheats.

3. Passenger bodywork

There are two general considerations in the design of passenger bodywork:

(i) the seating arrangement should be designed to give a low centre of gravity, and hence high stability to the loaded vehicle. However it must also provide a reasonable degree of seating comfort, and allow convenient entry and exit of the passengers;

(ii) the seating arrangement should be designed to prevent overloading when the vehicle is fully loaded with passengers and their goods.

There are two basic types of passenger bodywork. The first consists of two longitudinally arranged bench seats, which may be padded, facing inwards and allowing the passengers to sit in rows (Figure A2.1). The two bench seat bases are usually positioned over the rear wheels with a sunken platform between them for the passengers' feet. The rear of the vehicle is usually open to allow easy access to and from the benches. The second option is to mount bench seats laterally across the vehicle (Figure A2.2). Guard rails or extended back-rests are often fitted to the benches for the increased safety and comfort of the passengers. Full weather protection is frequently employed on passenger-carrying vehicles.

4. Cargo containers

The type of cargo container fitted to a low-cost motorized vehicle will have a major effect on its practicality and convenience in a particular application. The specification of the cargo container is therefore of crucial importance in determining the popularity, usefulness and economic efficiency of a vehicle design.

The height of the load affects the dynamic behaviour of the vehicle - the lower the centre of gravity, the more stable it becomes. The base of the cargo container should not be positioned too low, however, as this will limit the ground clearance and reduce the vehicle's ability to traverse rough terrain.

General-purpose cargo containers A large proportion of low-cost motorized vehicles, particularly those owned by rural families, are used for carrying a variety of different cargoes. For such applications a general-purpose cargo container is appropriate. The simplest, cheapest and lightest type of cargo container is a flat platform. This arrangement is suitable for carrying sacks, small drums and other cargoes that are in some form of container. It is preferable if the load is tied down. The flat platform is best constructed as a rectangular steel frame with either wooden planks or additional steel members and sheet to form the decking. Angle section steel is often used to fabricate the frame because it forms a slightly sunken platform which is ideal for accommodating wooden planks. The frame can either be welded or bolted to the vehicle chassis. Figure A2.3(a) shows a rectangular steel frame mounted to an A-frame trailer chassis.

A popular form of general-purpose cargo container for a low-cost vehicle is an open-topped box made from sheet steel. This is, essentially, a simple platform with sides added (Figure A2.4). This arrangement allows loose loads such as earth, sand or agricultural produce to be carried, and is also convenient for carrying packaged goods without tying them down. The sides and base of the cargo container usually need to be supported by additional frame members. If the cargo container sides are rigidly mounted, they will give additional support to the side members.

Box containers can be provided with a removable or hinged tail-board and sides to facilitate loading and unloading, but this will reduce the overall rigidity of the structure unless the catches which hold the tail-gate in the closed position are well designed and securely located. Containers can also be fitted with lids to increase the security of the cargo. The addition of extended sides as fitted to the three-wheeled vehicle in Figure A2.4 will increase the carrying capacity for a low-density load.

Sheet steel is a very suitable material for cargo containers. It can be formed into a wide variety of shapes. Sheet steel containers need to be adequately braced for support, and folding the upper edges will improve their rigidity. Zinc-coated (galvanized or GI) steel is resistant to rust and is very useful for carrying water or food. Glass-reinforced plastic (GRP), commonly referred to as 'fibreglass', is a very useful material for load containers, but is not widely available in most developing countries, and is often expensive. However, it is very useful for producing containers or tanks for carrying drinkable liquids (milk, water) or unpackaged food. The production processes used to make GRP containers naturally provide smooth surfaces and well-rounded corners, making them easy to clean. GRP load containers are unlikely to be as durable as steel or wooden ones, however.

Special-purpose cargo containers Special-purpose cargo containers are required on vehicles which are purchased for a specific application. The fitting of a special-purpose container will normally increase the cost of a vehicle compared with a simple general-purpose design. Important types of specialised containers are covered below.

Tank Tanks can be used to transport a range of liquids - kerosene, oil, petrol, agricultural chemicals and water. The design shown in Figure A2.5 can be made from galvanised sheet steel if a clean container for drinking water is required. A tank can be produced by modifying a standard 200 litre oil drum. This modification requires a cap to be added to the top of the tank, for filling the container. A further modification is to

include a 'baffle'. A baffle is a plate built into the tank. It prevents rapid movement of the liquid from one end of the container to the other, which can affect the stability and balance of the vehicle. A gap must be left at the bottom of the baffle to allow the tank to be emptied. A standard tap fitting, attached to the rear of the tank, allows liquids to be emptied easily.

A cradle fitted to the tank will allow it to be easily attached to or detached from the vehicle chassis and ensure that it is held in the correct position.

Insulated box Insulated boxes fitted with lids can be used for distributing and selling a range of perishable goods, including milk, fish, ice-cream, cold drinks, etc. The design illustrated in Figure A2.6 is made of GRP. The material is well suited to this application, as the internal surfaces can be easily cleaned, but wood or steel with painted surfaces can also be used. The important feature of insulated boxes is the space between the inner and outer containers which is filled with insulating material which inhibits the change of temperature of the load. Polystyrene foam (used for packing fragile products) is a good material, but may be difficult to obtain. Sacking, scraps of cloth or wood shavings, etc., are possible substitutes. This type of container should be constructed so that it can easily be removed from the vehicle. This will enable other loads to be moved if the transport of perishable loads is only a seasonal requirement.

Tipping cargo container When moving large quantities of loose materials, for example on a construction site, a great deal of time can be saved by using a vehicle which will tip to unload. The cargo container must have a hinged or removable tail-board, and the container frame must pivot relative to the longitudinal chassis members. Figure A2.3(b) shows the construction of a light trailer with a tipping cargo container. The platform of the cargo container must be relatively high off the ground to give a sufficient angle of tip to ensure that the material is fully discharged.



Fig. A2.1 Passenger body with longitudinal seating



Fig. A2.2 Passenger body with lateral seating

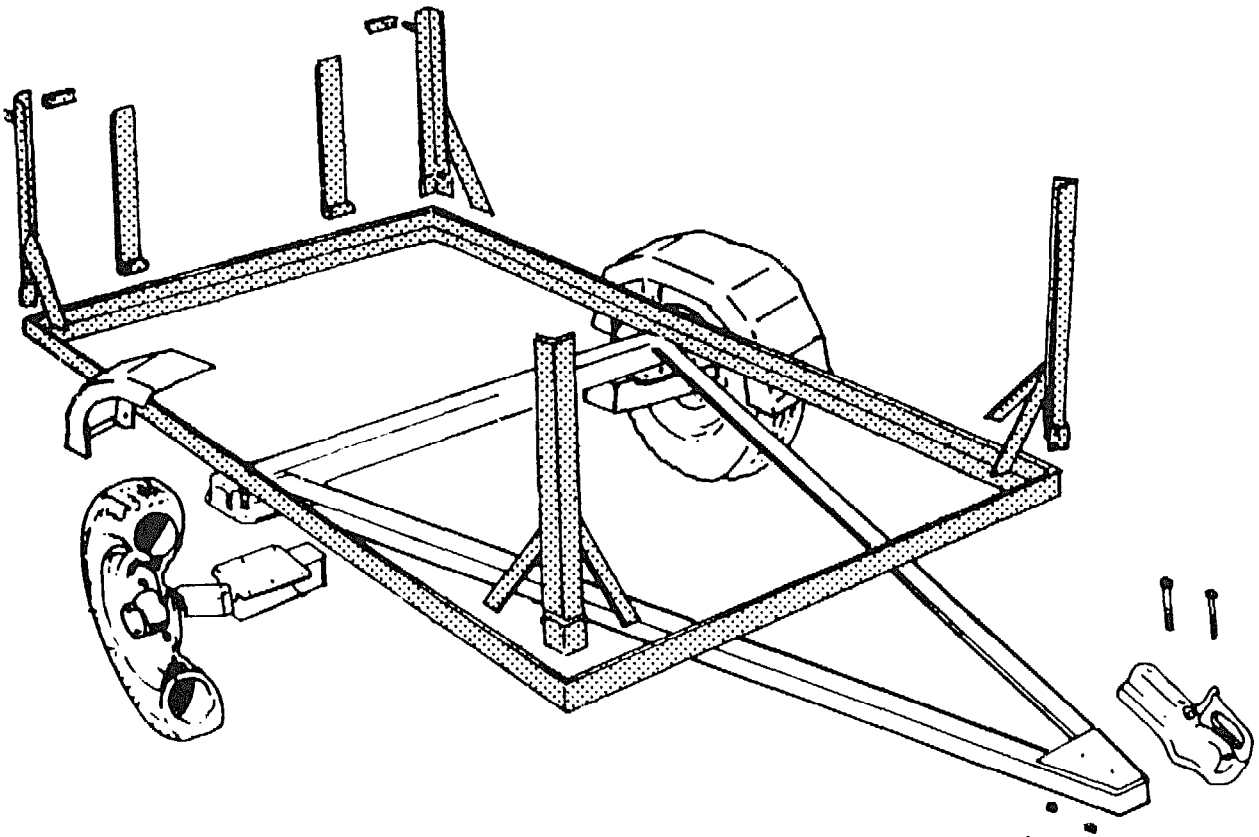


Fig. A2.3 (a) Rectangular frame mounted on A-frame chassis

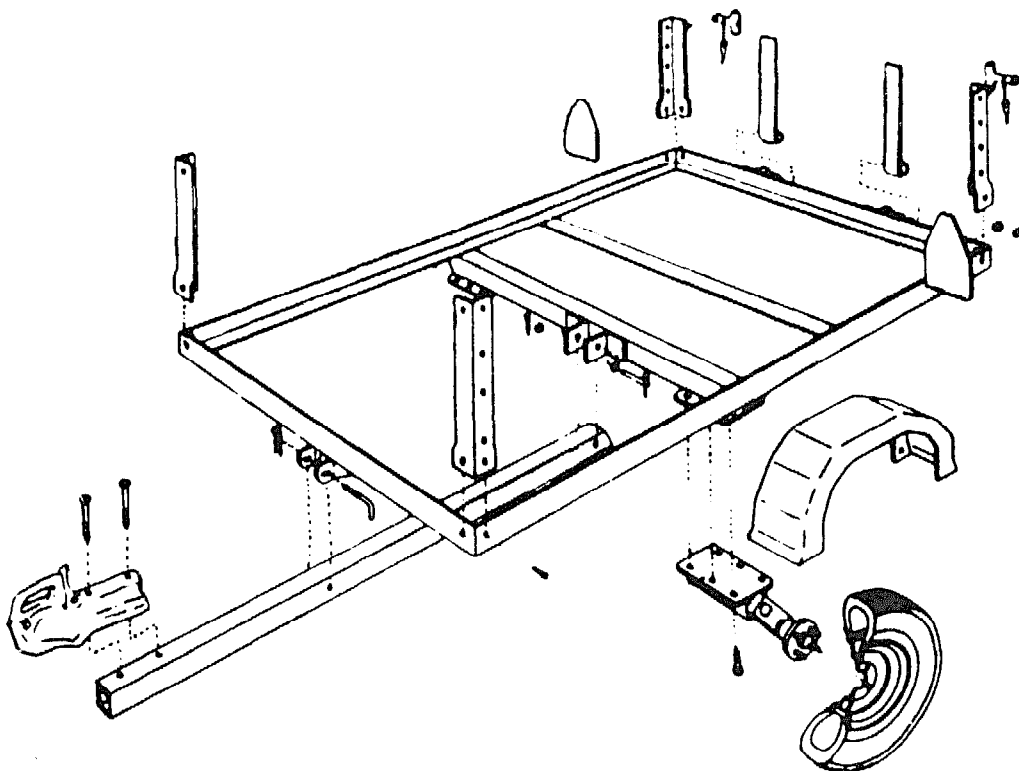


Fig. A2.3 (b) Trailer chassis with tipping body

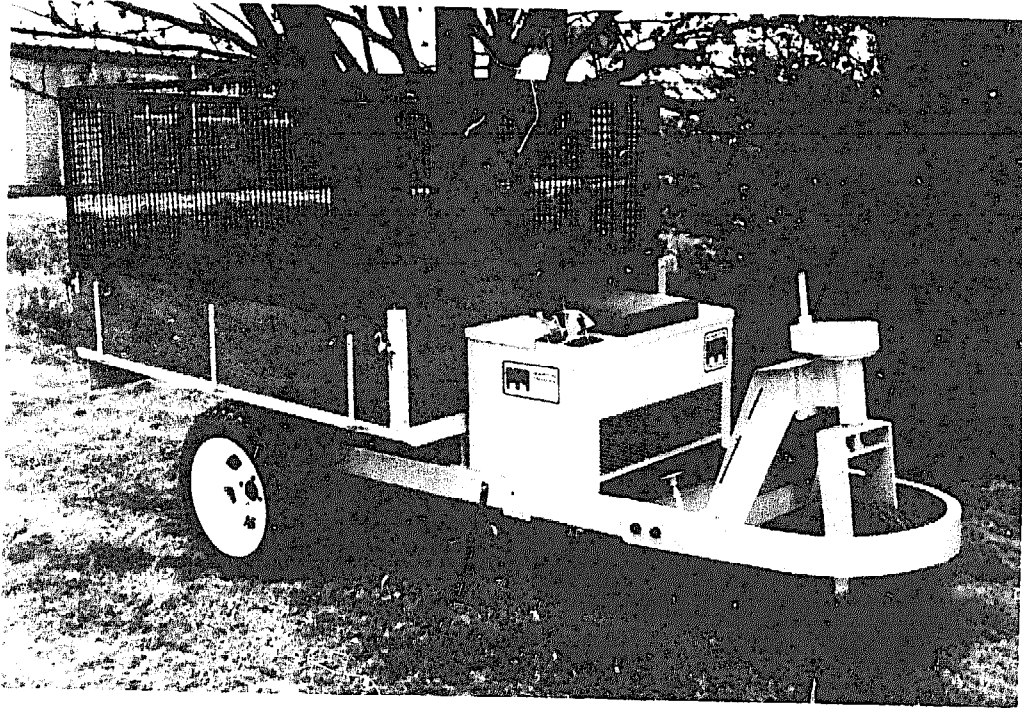


Fig. A2.4 Open-topped box body with extended sides

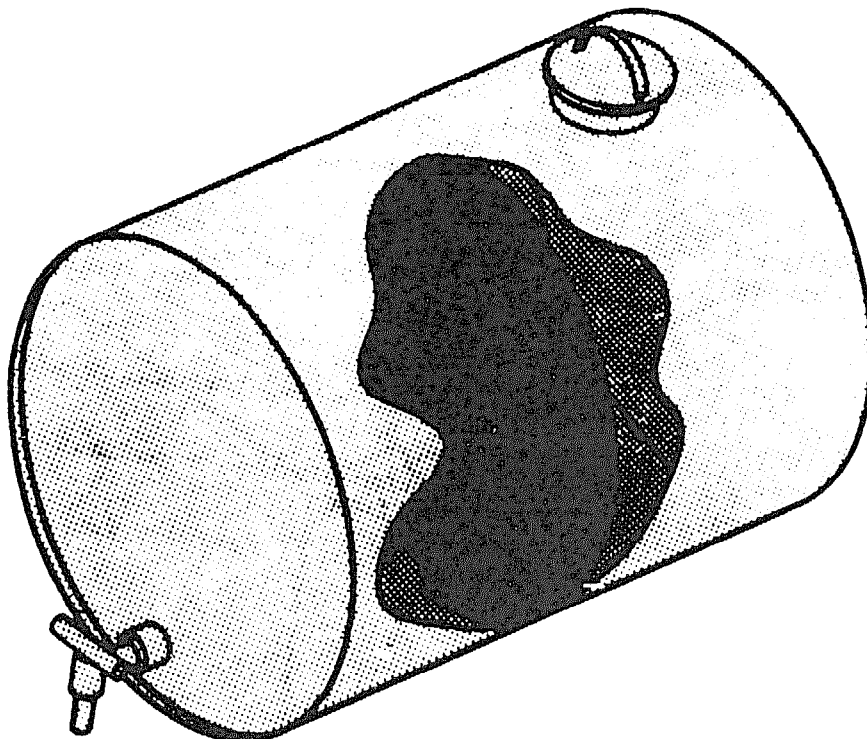


Fig. A2.5 Liquid tank showing 'baffle'

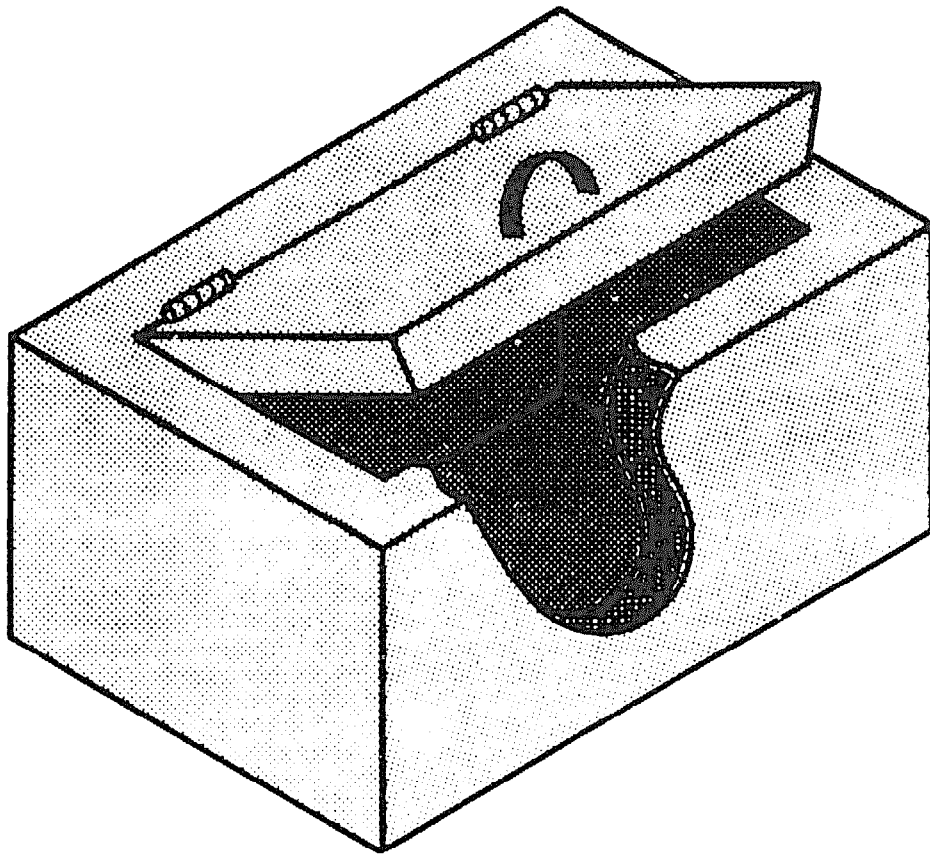


Fig. A2.6 Insulated box

SUSPENSION

The vibration and shock loads imposed on a vehicle by road surface irregularities can cause discomfort to the occupants, damage a fragile load and subject the structure to excessive stresses. Suspension is employed to reduce the extent to which these loads are transmitted to the vehicle structure, but in such a way as to minimize the adverse effect on vehicle stability. On some types of low-speed, low-cost vehicle no suspension is used. For example:

- a traditional, Indian wooden-wheeled bullock cart has no suspension system and no means of reducing the loads transmitted by the road to the cart;
- a bicycle has no suspension system and relies on the resilience of the pneumatic tyres to reduce the loads transmitted to the vehicle.

However, because low-cost motor vehicles travel at higher speed than non-motorized means of transport it is necessary in most applications to fit suspension systems. The use of a suspension system is particularly important on vehicles regularly used on rutted, uneven roads and, generally, the need is greater on vehicles using small diameter wheels.

The suspension system of a low-cost motor vehicle will usually consist of springs and mechanical linkages which control the relative motions between the wheel-and-axle assemblies and the chassis. Most suspension systems also use dampers, sometimes called shock absorbers, in conjunction with springs. These devices are required to cause a rapid reduction of (or to damp) vibrations that tend to be induced in a sprung assembly.

This chapter discusses the characteristics of different types of springs and dampers, and then how they are incorporated into different suspension systems.

1. Springs

Suitable types of spring for the suspension of low-cost vehicles are: leaf, coil, torsion bar and rubber. Except for the last type, the springs are normally made of steel. The production of steel springs is a specialized activity requiring special equipment. The specification of the material from which a spring is made directly affects its performance. Specifically, steels used for making springs must have a relatively high carbon content - typically between 0.6% and 0.9% - and must be suitably heat-treated to give the correct spring characteristics. Springs are usually subjected to a process called 'scragging' which involves overloading them in a precise manner to increase their service life. Shot peening and anti-corrosion treatments are also often employed for the same purpose.

Many low-cost motor vehicles will therefore use springs supplied by specialist manufacturers, or from conventional motor vehicles such as cars, commercial vehicles or motor cycles. An understanding of the suitability of a particular spring to be used in a certain application can be gained from considering its performance when used on a conventional motor vehicle. This will provide basic information on the spring's

ability to support loads and the specification of the required mechanical linkages. However, because the weights of, and the loads carried by, low-cost vehicles are generally lower than motor cars and commercial vehicles, it is often necessary to adapt standard springs. This can be done by, for example:

- removing some of the leaves from a leaf spring;
- reducing the length of a coil spring or torsion bar.

However, this must be done carefully to ensure that the final spring has the correct characteristics for the vehicle application. Also, it is important to avoid applying excessive heat which will alter the heat-treated properties of the steel, and hence its springing characteristics.

Leaf Springs The most common application of leaf springs on conventional vehicles is to support the rear axle (Figure A3.1 shows the beam axle of a low-cost vehicle equipped with leaf springs). They are rarely used on modern motor cars but remain very common on commercial vehicles. The most common form of leaf spring is the semi-elliptic type which is mounted on to the chassis at each end and supports the axle at its centre. There are several variants of this design in use but the principles of operation are similar. A leaf spring is constructed from several layers of steel strips to form a beam of laminated construction. The beam is supported by pivots at each end; one end also features a swinging shackle. The function of the shackle is to accommodate the variations in the length of the spring as it deflects. Figure A3.2 shows the main components of a typical semi-elliptic leaf spring.

When supported on pivots, a leaf spring is subjected to bending stresses rising to a maximum at the point of loading - this corresponds to the point of location of the axle in Figures A3.1 and A3.2. The leaves of a leaf spring are arranged to make optimum use of the spring material by distributing the bending stresses equally throughout the volume of the material. The leaves are strips which are cut to length as indicated in the diagram (Figure A3.3). The strips sometimes have pointed ends, as shown, to improve the distribution of the bending stresses throughout the spring. As a leaf spring deflects, there is a relative sliding motion between the surfaces of the leaves, and the friction between them tends to oppose this motion. This provides a degree of in-built damping which reduces the need for separate damping units. In an effort to control this friction, the spring leaves are often interleaved with plastic materials. Also, the springs themselves are sometimes wrapped and sealed to prevent the entry of dirt and water.

The ends of the longest, or master, leaf of a leaf spring are usually coiled to form the eyes for receiving the pivot or shackle pins. Sometimes, however, these eyes are forged on the ends or other special arrangements made. Rubber bushes are widely used in the eyes of springs for light motor vehicles, but metal bushes, with provision for lubrication, are necessary for very heavily loaded springs. Nylon or self-lubricating bearings can be used in place of rubber types, although they are not as effective at reducing the transmission of high-frequency vibrations to the chassis.

A single bolt, usually in a vertical hole through the centre of the spring, holds all the leaves together. Four additional bolts, or two U-bolts, are used to clamp the spring to the axle. The axle can be mounted either on top of the springs, or beneath them. Various methods have been used to locate the leaves positively within the pack. The leaves



Fig. A3.1 Low-cost vehicle with live beam axle suspended on leaf springs

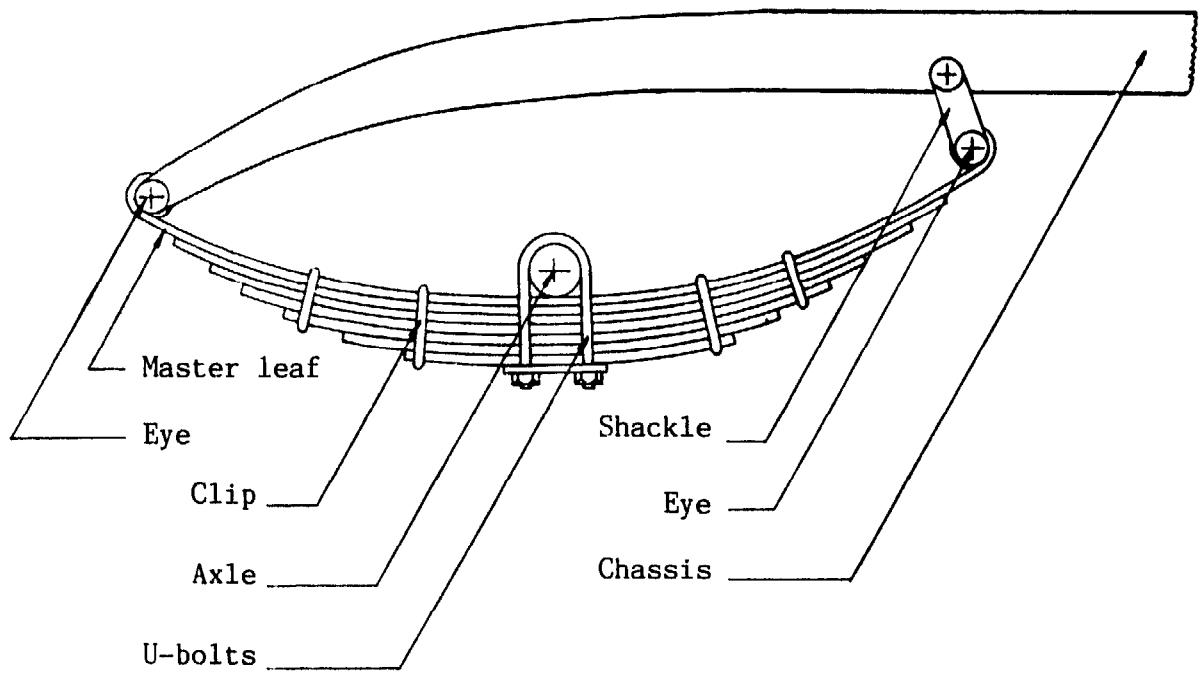


Fig. A3.2 Components of semi-elliptic leaf spring

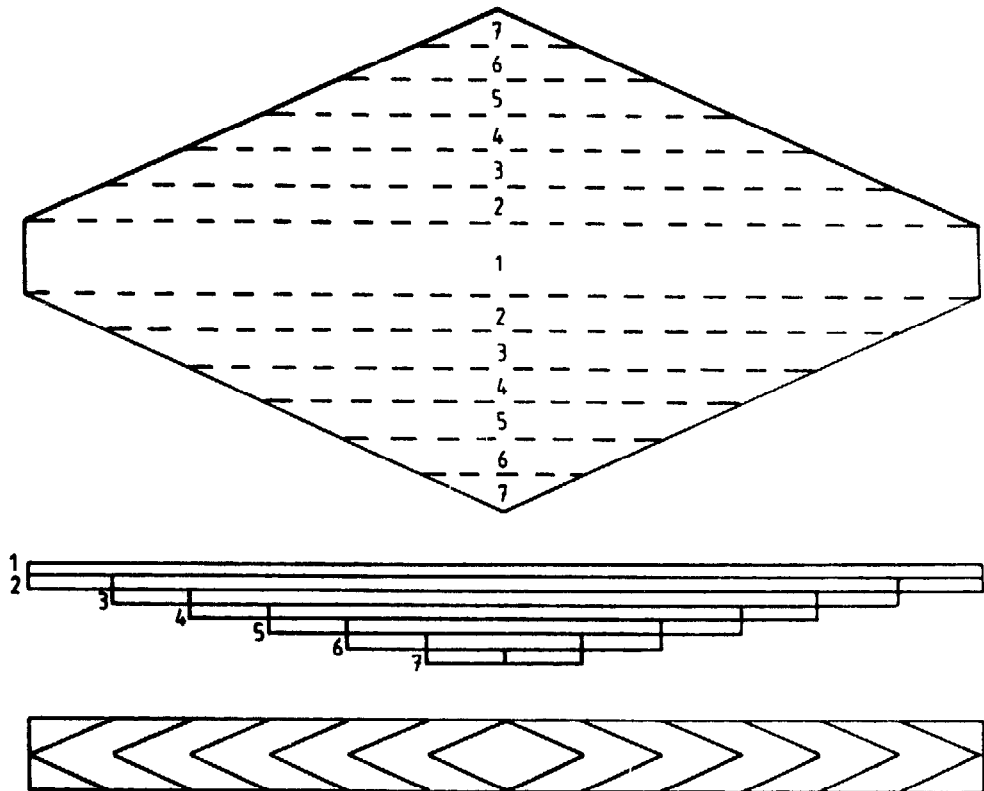


Fig. A3.3 Dimensional arrangement of leaves of spring

sometimes incorporate small projections which mate with corresponding recesses in alternate leaves. Clips which fully embrace the leaves are also used to prevent displacement.

As well as providing springing to the axle, the leaf spring serves to guide it. Fore and aft movement of the axle is limited by the leaf spring and on a low-cost motorized vehicle no additional suspension linkage members are required.

Leaf springs from commercially produced motor vehicles can be modified to give softer springing for use on a light-duty, low-cost vehicle. This is best accomplished by removing alternate leaves so that the depth of the spring is approximately halved. It is very important that the lengths of the individual leaves are arranged to be progressively shorter, thereby forming a triangular shape for uniform stress distribution.

Coil springs Coil springs are the most widely used type for vehicle suspension systems. They have the advantage of fitting into a compact space and have four times the energy storage capacity for a given weight than leaf springs. Figure A3.4 shows a typical example. One end of the coil spring is attached to the chassis, and the other end to a linkage that connects the wheel-axle to the chassis.

Damper units are often mounted inside coil springs with pivots at each end. Figure A3.5 shows the internals of such a coil spring/damper unit. This arrangement is especially common on motor cycle rear suspension systems and on the front suspension of motor cars.

Coil spring/damper units from either scrap vehicles or a commercial supplier are often useful for incorporating into the suspension of a low-cost vehicle. The stiffnesses of coil springs vary widely between vehicles, however, e.g. a spring/damper unit from a motor car suspension is likely to be designed for higher loads than that of a motor cycle. The suspension geometry affects the degree to which a coil spring is loaded. This is discussed further in Section 3 of this Annex.

One method of stiffening a suspension system is to mount additional coil spring/damper units. Figure 3.19 shows a motor cycle sidecar fitted with two units. Figure 3.18 shows a motor cycle, equipped with a sidecar, with four units mounted to its trailing arm.

Rubber springs Several types of rubber spring can be used on low-cost motor vehicles. They are not commonly fitted to conventional motor vehicles, but they do have certain advantages:

- (i) rubber can be moulded to almost any shape;
- (ii) it can be bonded to metal parts very firmly, making attachment to the other parts of the suspension system simple;
- (iii) by suitably varying the 'mix' or by the addition of fillers, it can be endowed with a great amount of inherent damping capacity through the absorption of energy by hysteresis (internal friction) which can eliminate the need for separate dampers. This action generates heat in the rubber, however, and therefore the system must be designed so that severe conditions do not cause too much softening.

The fatigue strength of rubber is best in compression. Subjecting rubber to tensile loads tends to result in the development of cracks. One disadvantage of rubber is that the magnitude of the working range is

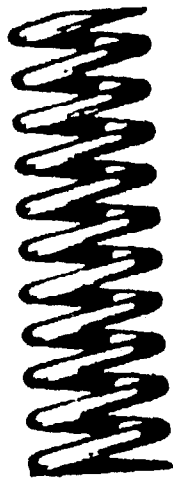


Fig. A3.4 Coil spring

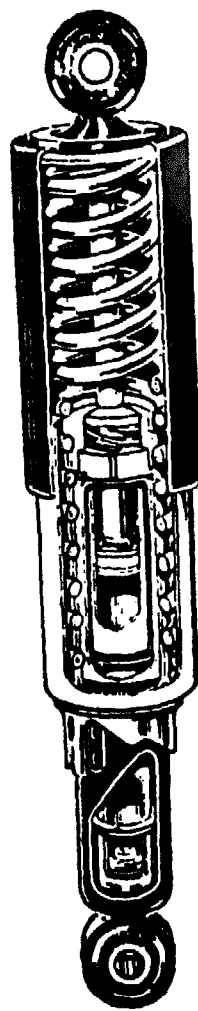


Fig. A3.5 Contained coil spring/damper unit

small and therefore it is usually necessary to incorporate a mechanical linkage that transfers the energy from a large deflection of a wheel to the small deflection of a rubber spring.

An efficient form of rubber spring which does this, and is much used on trailers, is the sprung arm unit. These are produced by a number of manufacturers, and a diagram showing the internal construction of a unit produced by Indespension is shown in Figure A3.6. The basic design principle employs a square-section solid beam inserted into a hollow axle beam of box section at an interior face angle of 45 degrees. A rubber roller, or cord, is located in each of the four resulting triangular-shaped spaces (Figure A3.7). To the outer end of the solid inner beam is attached an arm, on to which the stub axle is welded, whilst the opposite end of the inner beam is 'free' inside the enveloping hollow box section. When loading is applied to the stub axle, the inner solid beam rotates inside the hollow outer beam, thus compressing the rubber rollers. The sprung arm units are usually mounted one at either end of a non-driven beam axle. Their use provides effective independent suspension with a degree of integral damping for good ride characteristics. The units are light, durable and require no maintenance. They are available with different load ratings and to suit a variety of types of motor car hub assemblies. They are produced by a number of manufacturers (see Chapter 8).

Many suspension systems incorporate a small block of rubber called a 'bump stop' to limit the travel of the axle. This prevents the axle from hitting the chassis when subjected to large shocks. Bump stops may be attached either to the top of the axle, as shown in Figure A3.9, or to the underside of the chassis, as in Figure A3.10.

2. Dampers

Dampers function by opposing motion, the magnitude of the resisting force increasing with the velocity of the motion. Without dampers, the vehicle will tend to sustain a regular bouncing motion due to the elastic nature of its springs. As well as being unpleasant for the occupants, this significantly reduces the efficiency of the suspension and severely impairs the stability of the vehicle. The degree of damping offered by a damping unit should be matched to the stiffness of a suspension system for optimum performance. Generally, stiffer suspensions are needed for high vehicle loads and require more damping to oppose the higher forces involved. Modern dampers are usually telescopic hydraulic struts (Figure A3.8) that are interposed between the chassis frame and axle or, less frequently, of the lever type (Figure A3.9), which are also hydraulic units. Friction dampers give inferior performance to hydraulic types but are much simpler to produce. The friction damper shown in Figure A3.10 uses a sandwich arrangement of alternating flat discs of steel and friction material, the whole assembly tightened by an adjustable dished spring. Two levers in a V-formation, attached by pivots to the axle and chassis frame, produce relative angular movement between the steel and friction discs, thus providing a damping action. In a locally produced item, conventional brake lining material can be used to make the friction discs.

3. Suspension systems

It is important to choose a suspension system with the capacity to match the maximum load likely to be carried by the vehicle. A suspension system

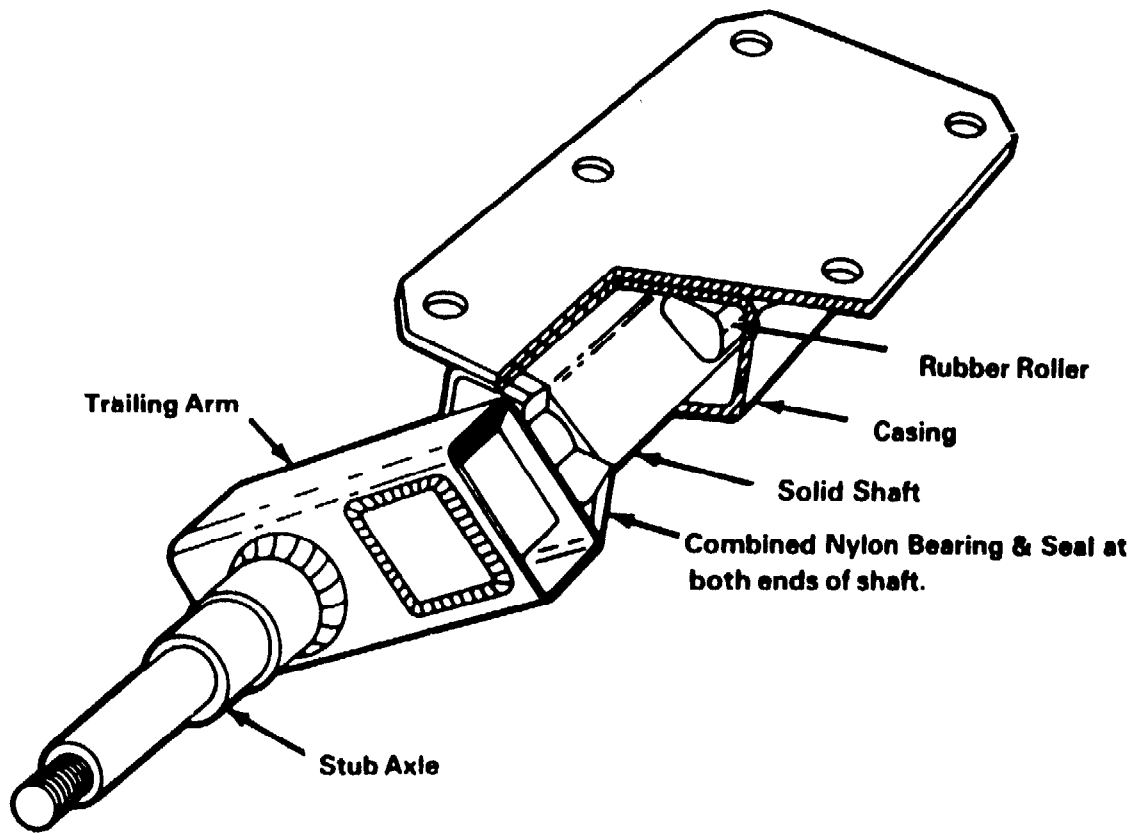


Fig. A3.6 Construction of rubber spring trailing arm suspension unit

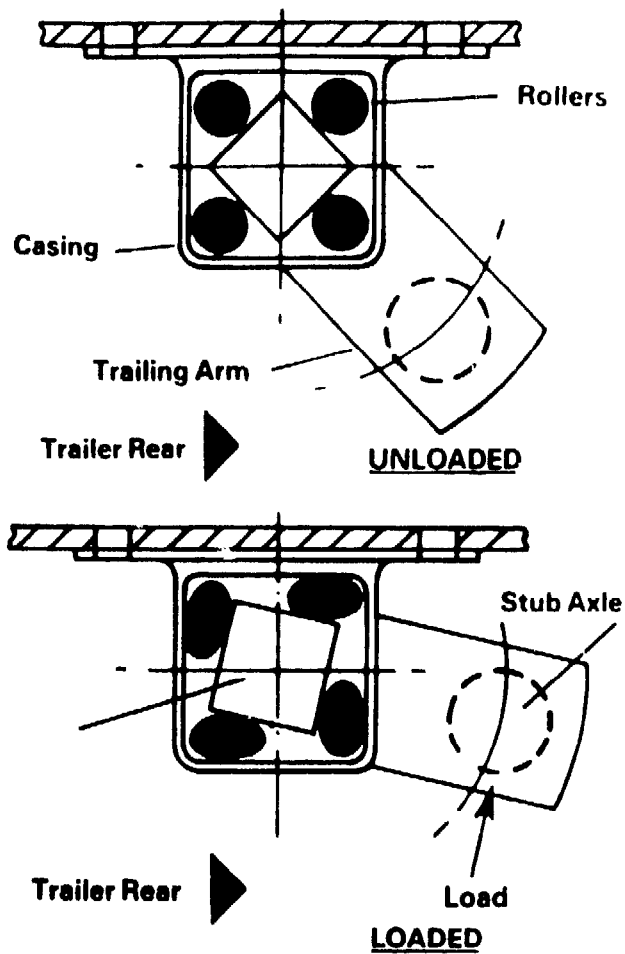


Fig. A3.7 Operation of rubber spring trailing arm suspension unit

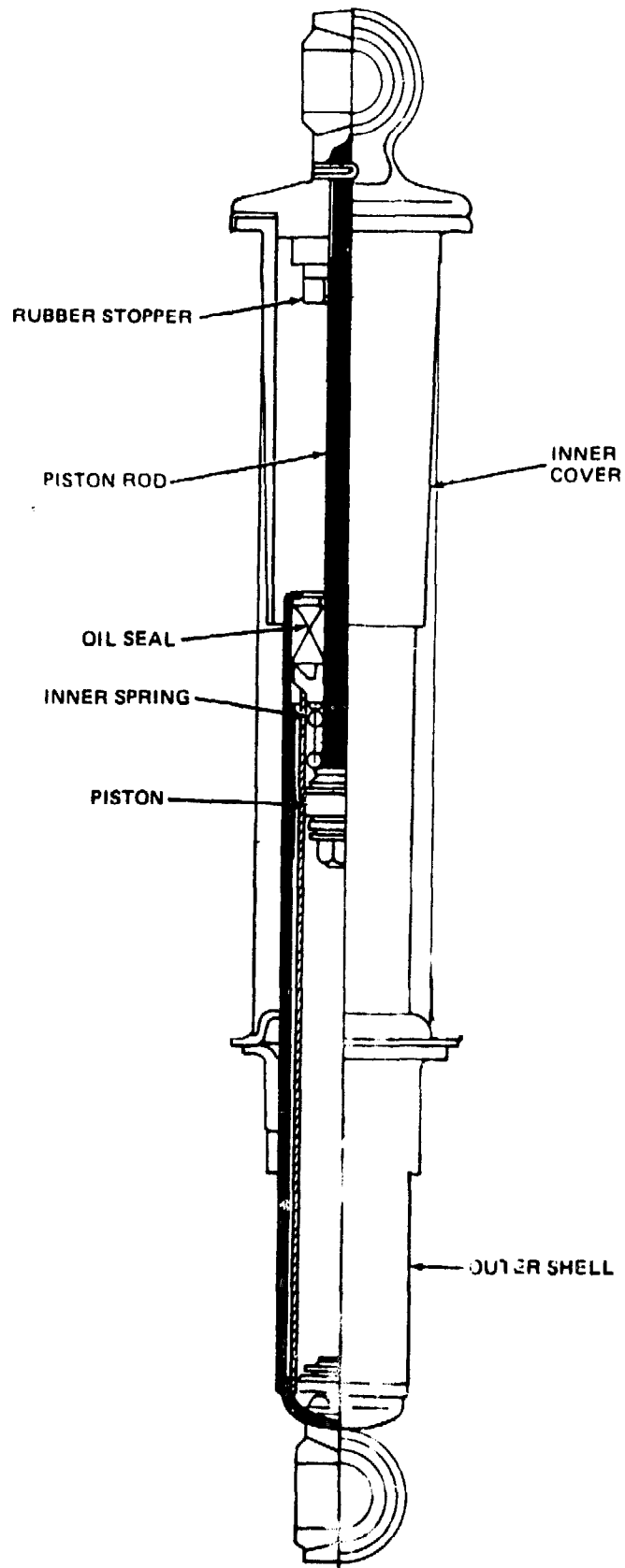


Fig. A3.8 Telescopic damper

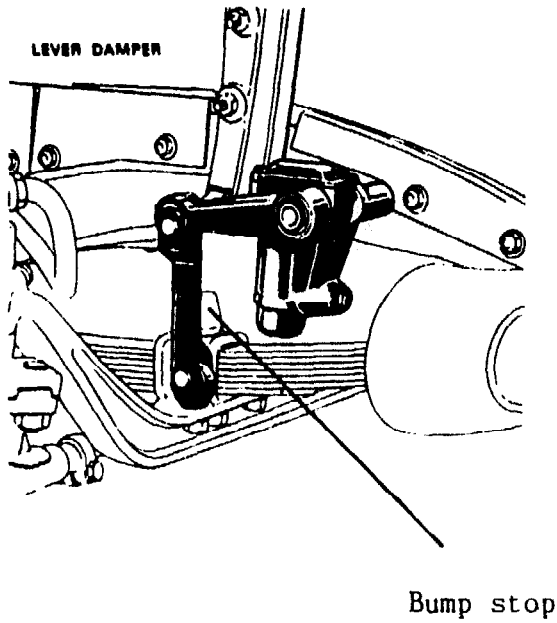


Fig. A3.9 Lever arm damper

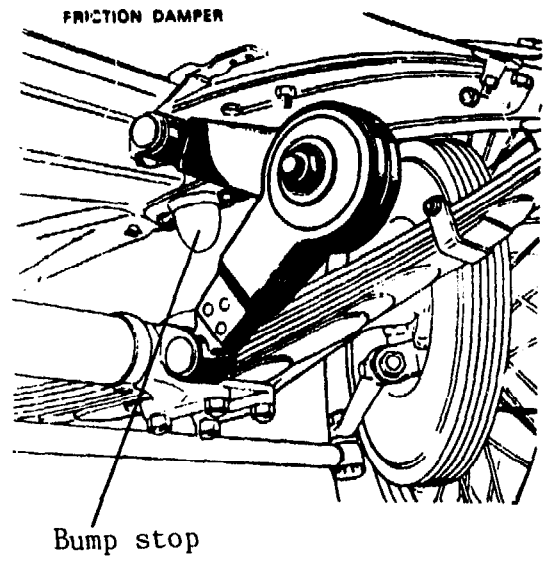


Fig. A3.10 Friction damper

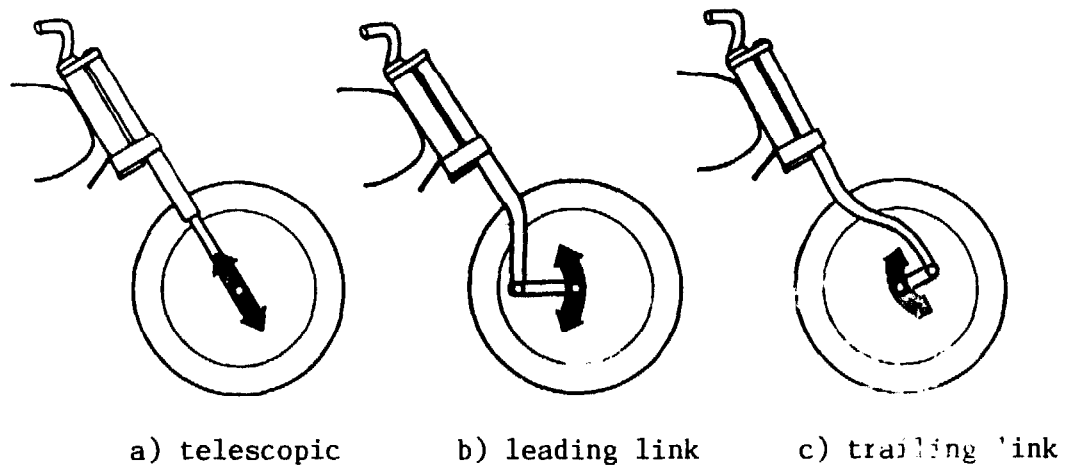


Fig. A3.11 Types of front fork suspension system

that is too soft will constantly 'bottom out' and will be inefficient at reducing the transmission of large shock loads to the vehicle. Too soft a suspension is also likely to result in damage to the vehicle structure. Too hard a suspension will result in a harsh ride, and minor irregularities of the road surface will cause excessive vibrations to be transmitted to the vehicle.

In selecting suspension systems for a vehicle, it is necessary to consider front and rear, and driven and non-driven, wheels separately. A further consideration is the configuration of the vehicle (three- or four-wheeled, sidecar, trailer, etc).

Suspension options are analysed here in terms of:

- rear suspension;
- front suspension;
- independent suspension.

However, it is necessary first to define different types of axle. Generally any shaft supporting a revolving wheel is referred to as an axle. The axle may carry a single wheel, or be a **beam** axle mounted transversely across the width of the chassis of a vehicle, supporting two wheels, one at each extremity.

A **dead** axle is one that does not rotate, but simply acts as a structural member supporting a wheel or pair of wheels. A **dead beam** axle consists of a structural member with a hub at each end to which the wheels are attached.

A **live** axle is one that rotates with the wheel or wheels. The axle rotates in bearings, which are mounted on the suspension linkage or in a housing that forms part of the axle assembly.

Rear suspension Many types of low-cost motor vehicle have a **pair** of rear wheels on the same axis:

- three-wheeled vehicle with single front wheel;
- four-wheeled vehicle of conventional configuration;
- four-wheeled conversion of motor cycle.
- two-wheeled trailer.

The pair of wheels can be mounted on a beam axle (which we consider here) or suspended independently (discussed under independent suspension, below).

The simplest form of beam axle rear suspension is where the pair of wheels is not driven (e.g. on a trailer, a four-wheeled conversion of a motor cycle, or a three-wheeled vehicle with single, front-wheel drive).

A non-driven rear axle is simply fabricated by welding a hub to either end of a steel structural member to form a dead beam axle. The fabricated beam axle can be mounted rigidly to the chassis but it is more common to use a simple suspension system. The simplest system is to support the axle on two semi-elliptic leaf springs, one at either end. This does not require any complex linkages, and the inherent friction in the springs may provide sufficient damping, though separate dampers can be fitted at each end of the axle. One end of each damper is attached to the axle, the other to the chassis. The simplicity of this configuration makes it the most suitable type for many low-cost motorized vehicles. A number of manufacturers produce a wide range of complete rear beam axle and wheel assemblies for low-speed vehicles (see Chapter 8).

For a driven rear axle, the suspension system is related to the type of transmission used. For a shaft drive, a live beam axle will be used with a final drive unit at its centre. This type of axle can be suspended in the same manner as described above (see Figures 4.18 and A3.1). It is possible to adapt most types of rear axle assembly from a rear-wheel driven motor car or light commercial vehicle to fit the chassis of a low-cost motor vehicle. However, it is important to adapt the complete axle/suspension assembly including the original springs, linkages, dampers, etc. Brackets and mounting points should be incorporated on the chassis to accommodate the assembly in a similar manner to the original. The suspension system of the new vehicle will then have a load-supporting capacity comparable to the original vehicle. A wide variety of different spring and linkage configurations are employed to attach the rear axle to a motor car chassis.

A chain-driven beam axle, without a differential unit, is also a live axle. However, it differs from the shaft-driven type in that there is no outer housing as part of the axle assembly to carry the bearings and act as the structural member. The driven axle or shaft also acts as the load-supporting member. In order to fulfil both roles, this type of beam axle is typically a hollow steel shaft of diameter substantially greater than that of a non-load supporting drive shaft. The axle support bearings should be positioned as close to the wheels as possible in order to minimize the bending stresses imposed on the beam axle by the chassis (see Figure 4.7). To accommodate any misalignment or deflections of the driven beam axle, it is desirable that it rotates in self-aligning bearings, which can be mounted in plummer blocks. These bearings are also better at resisting the axial loads experienced by the axle when the vehicle negotiates a corner than ordinary deep-groove bearings. The plummer blocks can be mounted directly to the chassis, perhaps through rubber blocks, but suspension is likely to be required and a leaf spring system as described above can be used¹. If a chain-driven beam axle is sprung mounted, the suspension system should limit the degree of permissible twist of the axle relative to the drive chain to prevent too much angular misalignment of the chain. The maximum angle of twist should not be more than a few degrees.

To overcome the problems of chain misalignment using a beam axle, an effective but complex alternative is to use independent suspension for chain-driven wheels. This is discussed subsequently.

Front suspension The complicating factor with front suspension is that the suspended wheel or wheels must also steer. For a four-wheeled vehicle the front wheel hubs, including the steering pivots, may be mounted on a dead-beam axle suspended by leaf springs, as described above, or suspended independently, which is discussed subsequently. Here we concentrate on suitable front suspension systems for a rear-wheel-driven three-wheeled vehicle.

In general, all front fork designs now used fall into one of three groups - Figure A3.11 illustrates each of these: a) telescopic; b) leading link; and c) trailing link - the path of the axle being indicated by the heavy lines and arrows. The most common form of single front wheel

¹ The details of fitting a leaf spring suspension to a chain-driven beam axle are discussed in more detail in Chapter 4 (Section 4.2.5).

suspension, employed on most motor cycles, is the telescopic fork. When fitted to a three-wheeled vehicle, a telescopic fork assembly from a motor cycle may not be stiff enough to accept the additional weight, especially when braking. However, it is usually possible to increase the spring stiffness of the forks by the addition of spacers to the springs. The forks should never be over-filled with damping fluid in an effort to modify their performance - this will only result in bursting the seals.

Leading link forks are fitted as standard equipment to some small motor cycles. Forks based on this design can be locally produced to create a heavy-duty front fork using motor cycle rear spring/damper units as sprung members (Figure A3.12).

A number of commercially produced scooters and small-wheeled three-wheelers feature a trailing link arrangement for the front suspension (Figure A3.13). The type of wheels and hubs used by these vehicles usually need supporting from one side only.

The action of the fork under heavy front braking is most important. Adverse disturbances can be set up, partly by the transference of weight to the front end which then occurs, and partly by local forces and deflections within the fork mechanism. If the line of action of the axle is rearwardly inclined, as with telescopic forks, the springs will compress considerably, and the vehicle will 'throw back' immediately it comes to rest. The reaction of leading and trailing link forks under braking is more complex.

Independent suspension The front suspension methods described above are all forms of independent suspension. However, here we are specifically concerned with the independent suspension of each of a pair of wheels. On low-cost vehicles independent suspension is most likely to be used on:

- the wheels of a motor cycle trailer;
- the wheel of a motor cycle sidecar;
- the driven rear wheels of a three-wheeler with chain drive;
- the rear wheels of a front-wheel-drive three-wheeler.

Two forms of independent suspension are relevant, trailing arm and swinging arm.

1. Trailing arm

In trailing arm suspension the wheel is mounted at one end of a member which is attached to the vehicle chassis by means of a pivot in front of the wheel. The movement of the trailing arm is controlled by means of a spring, or a spring and damper, attached to the arm and to the chassis. This form of suspension is used at the rear of most motor cycles, employing a combined coil spring/damper unit. Coil spring/damper units from a motor cycle can be used to control the movement of trailing arms on other low-cost vehicles but consideration should be given to their load-carrying capacities when mounting these units. Figure A3.14(a) relates to a simplified equation giving the compressive load on a spring/damper unit relative to its position and angle of mounting on a trailing arm, the equation being:

$$PL_1 = QL_2 \sin \theta$$

Where P = the load acting on the axle
Q = the force acting on the damper.

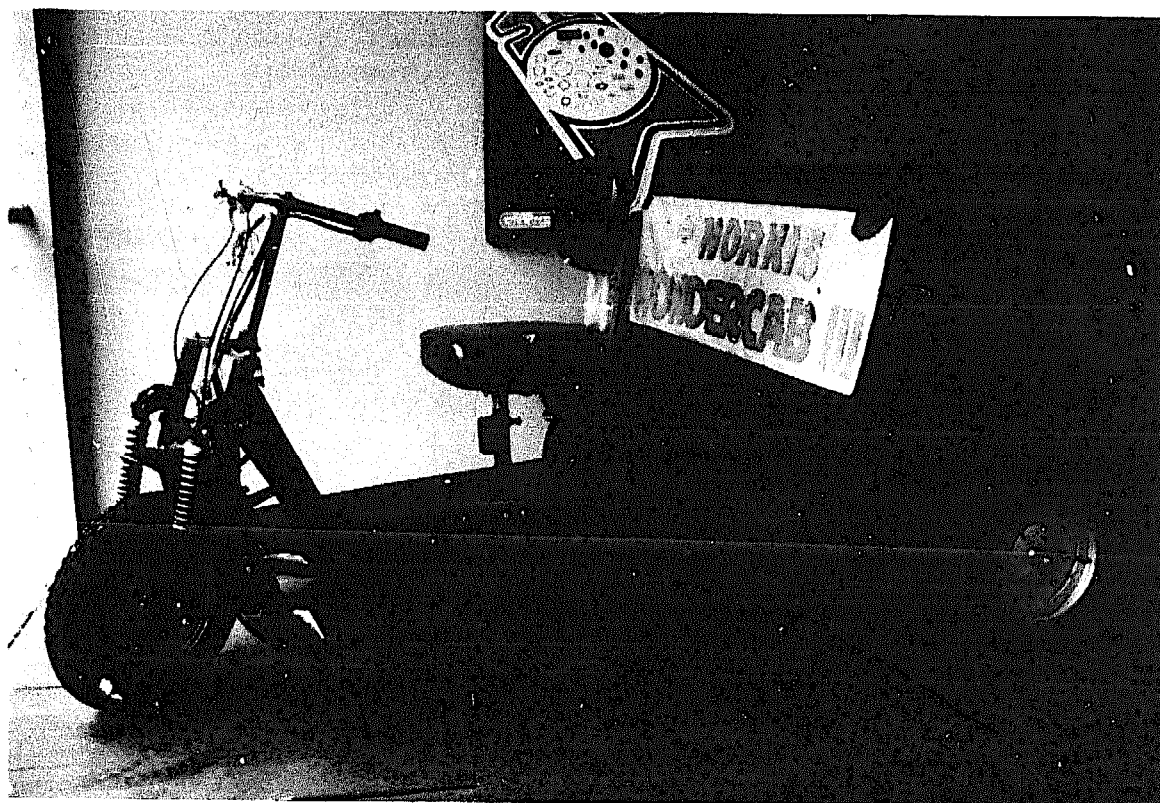


Fig. A3.12 Leading link front fork suspension using motor cycle coil spring/damper units

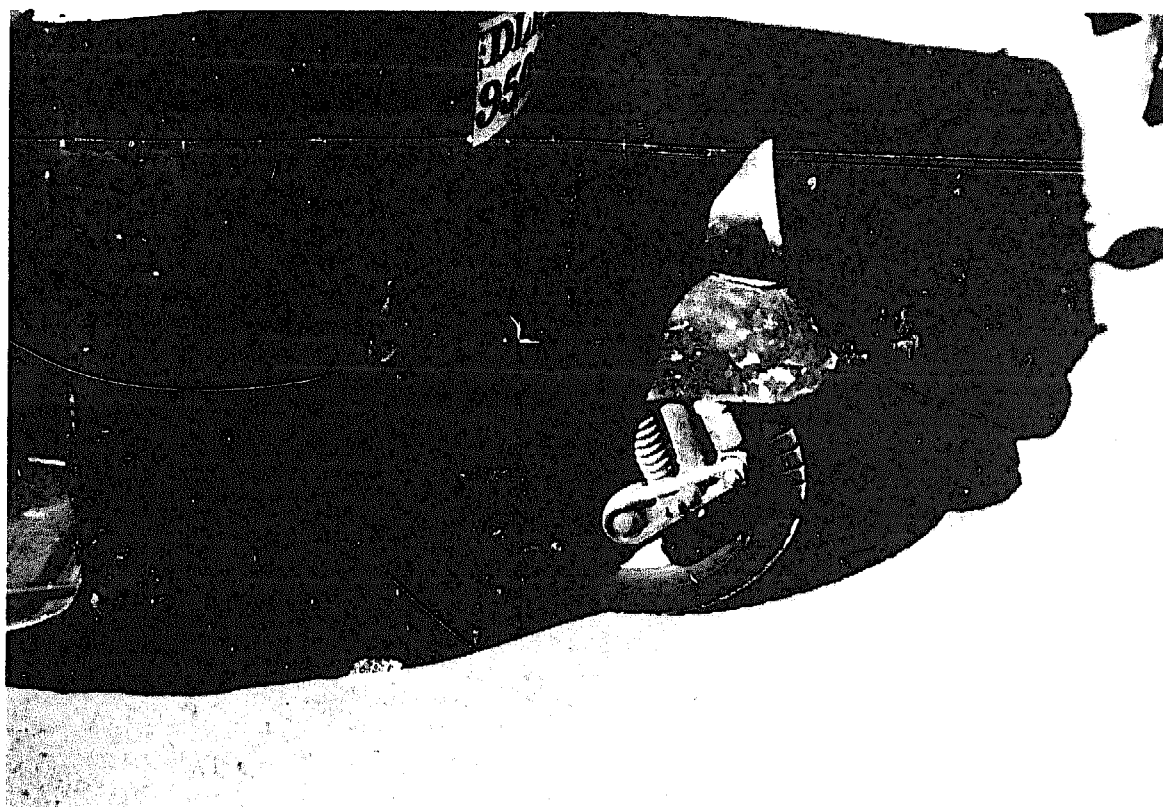


Fig. A3.13 Trailing link front fork suspension

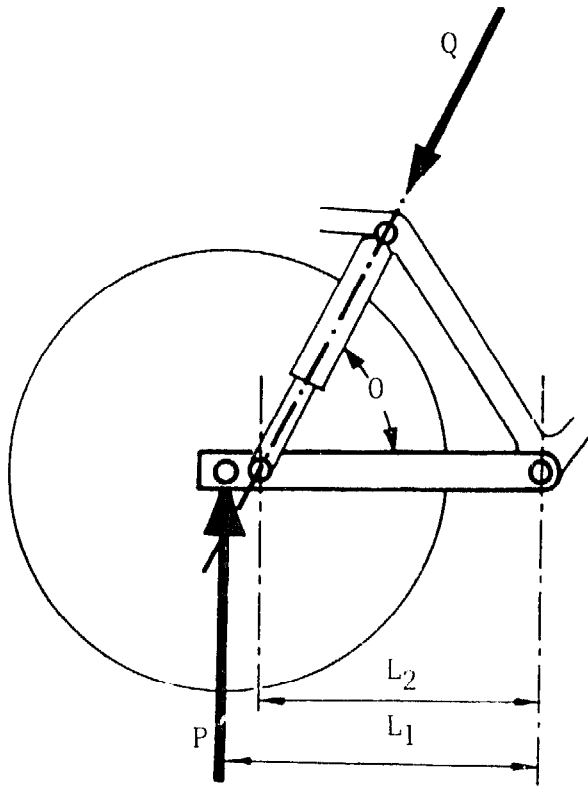


Fig. A3.14 (a) Trailing arm suspension

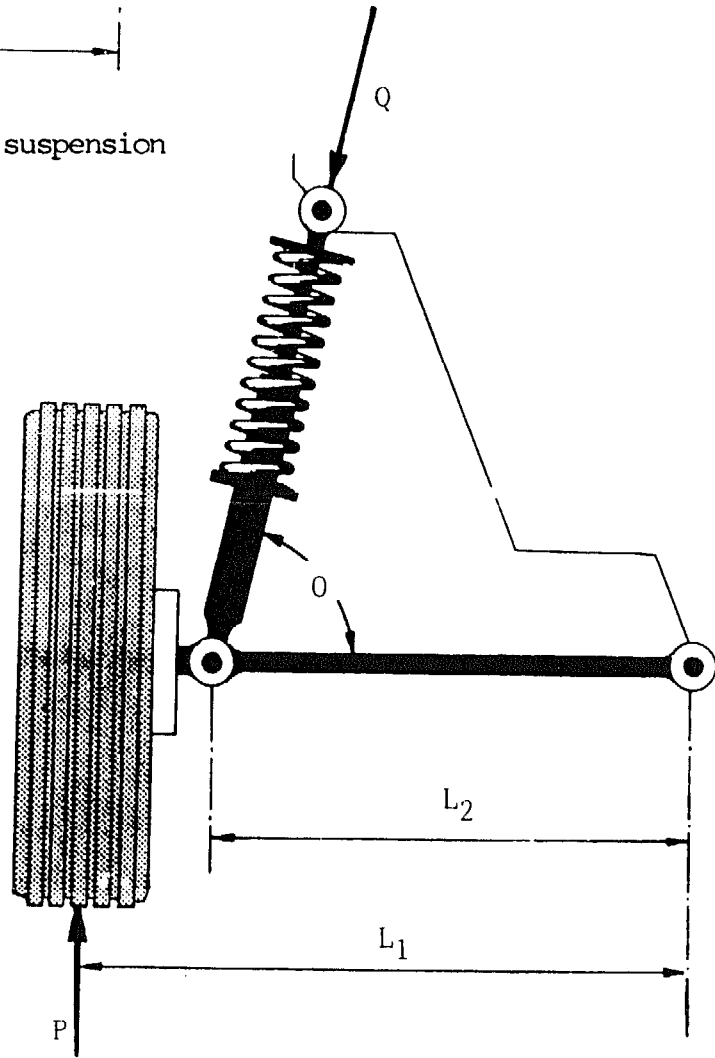


Fig. A3.14 (b) Swinging arm suspension

This equation assumes that the load P acts at 90 degrees to the trailing arm. Note that the angle θ will decrease as the trailing arm moves upwards.

Motor cycle damper units almost always feature flexible rubber bushes at either end for accommodating the frame-mounting lugs. These bushes have an important influence on the performance of the unit in that they permit a small degree of misalignment and reduce the transmission of high-frequency vibrations. They should not be replaced with bushes made from other material.

An effective, but complex, method of overcoming the problems of chain drive with a sprung beam axle is to mount the two driven wheels independently on trailing arms. This configuration has been exploited with success in India on the small Bajaj three-wheeled vehicle (see Figure A3.15 and Chapter 8). Each rear wheel is supported by a trailing arm. The drive chains run from sprockets on an intermediate shaft mounted parallel to the pivoting axis of the trailing arms and the chains lie parallel to the trailing arms with the driven sprockets affixed to the rear wheels. The Bajaj vehicle's trailing arms are made of cast aluminium and act as housings for the drive chains. Because both rear wheels are driven, a differential unit is incorporated on the intermediate shaft. The trailing arms are triangulated at the pivoting axis for lateral stability. If a suitable differential unit can be obtained, it is feasible to construct a similar rear suspension configuration using resources available locally.

2. Swinging arm

In swinging arm suspension the wheel is mounted at the end of a member which is positioned laterally under the vehicle chassis and attached to it by means of a pivot (Figure A3.14(b)). The movement of the swinging arm is controlled by means of a coil or leaf spring and a damper, attached to the arm and to the chassis. The same equation used for calculating the compressive load on a spring/damper unit for a trailing arm can also be applied to a swinging arm. Swinging arm suspension can be used on both driven and non-driven wheels. If a coil spring is used, as shown in Figure A3.14(b), an additional pivoted member is required to control the fore and aft movement of the swinging arm.

Sprung load container An alternative method to suspension for reducing the severity of shocks transmitted to the load-carrying structure of the vehicle is to spring-mount the load container itself (Figure 4.4).

The advantages of this technique compared to a sprung chassis are simplicity and low cost. Also, the final drive mechanism becomes less constrained because it need not allow for significant movement of the driven wheels.

The disadvantages of relying solely on a sprung load container to absorb shocks are that the oscillations of the load container are likely to be substantially increased to achieve the same degree of shock isolation as a sprung chassis. This motion may prove unpleasant for occupants of the vehicle, and if damping is inadequate may adversely affect the vehicle's stability. The vehicle chassis will not be as isolated from shock loading and will therefore be subjected to greater stresses. The stability of the vehicle, when traversing bumps and pot holes, will be reduced.

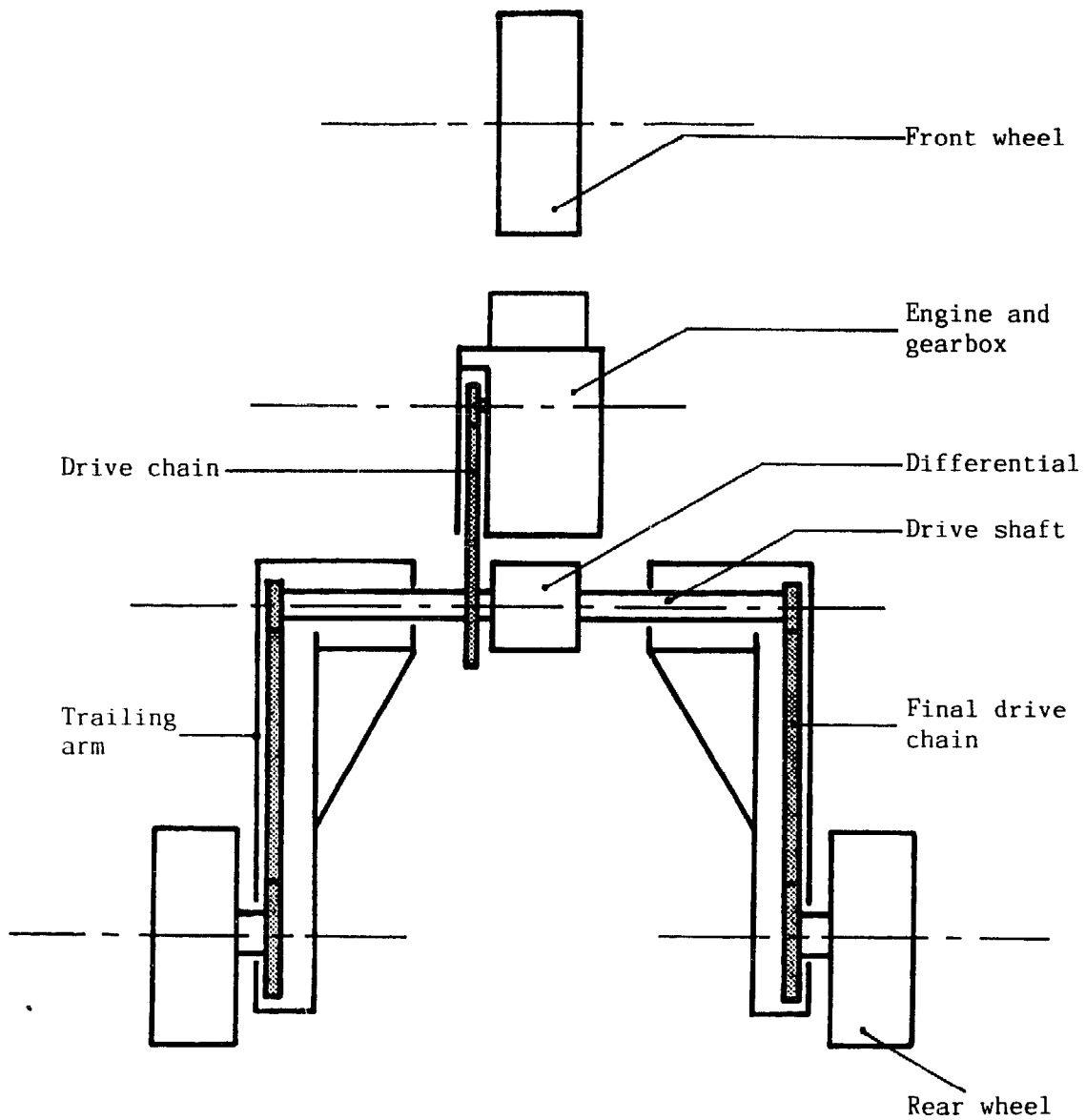


Fig. A3.15 Schematic view of Bajaj three-wheeled vehicle transmission system

The extent to which a load container is sprung mounted can vary widely. Small rubber spacers interposed between the load container and chassis give some reduction of high-frequency vibrations but will not much reduce large jolts. Rubber spacers can be made from old tyres and their attachment can improve the service life of load containers, particularly on lightweight types such as are mounted on motor cycle trailers. Large, soft rubber blocks and coil springs can both be used for the spring mounting of load containers. However, lateral sway of the load container may need to be controlled by the incorporation of side-mounted linkages connecting it to the chassis.

VEHICLE STABILITY AND CONTROL

1. Overall dimensions

The overall dimensions of a vehicle are influenced by its configuration, and the weight and volume of the payload it is expected to carry. All other things being equal, the larger the weight or volume of the payload to be carried, the greater will be the overall dimensions of the vehicle. Two of these have a particular effect on its stability and control:

1. The **wheelbase** of a vehicle is the distance between the centres of the front and rear wheels. A vehicle with a long wheelbase is generally more stable at speed but less manoeuvrable than a short-wheelbase vehicle.

2. The **track** is the distance between a pair of wheels on the same axis (e.g. the distance between the two rear wheels). If the height of the centre of gravity remains constant, an increase in track will give more stability to the vehicle when cornering. Too wide a vehicle will be less able to negotiate narrow routes and traffic-congested roads, however.

2. Centre of gravity

For maximum stability, the centre of gravity of a vehicle should be as low as possible. The main limitation on achieving a low centre of gravity is the need to maintain adequate clearance between the underside of the vehicle and the ground. This ground clearance may need to be considerable if the surface is very uneven. The positioning of the centre of gravity along the length of the vehicle also has an influence on stability. For a four-wheeled vehicle of conventional configuration, the centre of gravity should act mid-way between the front and rear wheels for maximum stability. For a three-wheeled vehicle the centre of gravity should be biased towards the axis with two wheels for maximum lateral stability. However, if the centre of gravity is too close to the pair of wheels, longitudinal stability will be impaired.

Apart from stability there are two other, often conflicting, considerations in determining the optimum position of the centre of gravity - traction and steering. The centre of gravity should be located so that there is a high enough proportion of weight acting on the driving wheels to prevent loss of traction on slippery surfaces and enough force on the steering wheel(s) to prevent tyre slippage when cornering. This is particularly important on front-wheel-drive vehicles where it is normal to bias the centre of gravity towards the front of the vehicle since, when travelling uphill, weight is transferred from the front wheels to the rear.

The relationship between the position of the centre of gravity of a two-wheeled trailer and the stability and traction of the complete vehicle is very complex. However, a simple rule to follow is that the centre of gravity of the loaded trailer should be slightly forward of the axis of the trailer wheels.

3. Steering response

The factors affecting the steering response of a wheeled vehicle are numerous. They include, in addition to the location of the centre of gravity, the following: the steering geometry; the size, type and inflation of the tyres; the suspension geometry; the spring rates and damper capacities; the amounts of tractive or braking torque applied to the wheels; and the moments of inertia about the three axes of the vehicle. The manner in which all these variables interact to affect the behaviour of a vehicle is very complex but certain trends in the effect of individual variables can be discussed.

One of the most important factors when considering steering geometry is trail. Figure A4.1 shows the geometry of a steered front wheel. The trail of the wheel, as shown in the diagram, is the theoretical distance between the tyre contact point and the intersection of the steering head axis at ground level, the tyre contact point being situated behind the steering head axis. Trail is important for stability since it gives the wheel a tendency to self-steer in a straight line whilst moving forward. The amount of trail affects the force required to steer the vehicle. If its value is small, the steering will feel very light and unstable and be badly affected by going over uneven ground at high speed. If the trail is large, the vehicle will require more effort to steer around corners but will remain stable at speed. The amount of trail is influenced by the castor angle which is the angle the steering column axis makes with the ground. For a given amount of trail there is an optimum castor angle which will result in the most desirable characteristics for a particular vehicle. Other factors affecting the amount of trail are the wheel diameter, the tyre section and inflation pressure.

Two-wheeled vehicles generally require more trail than three or four-wheeled vehicles because they are inherently less stable. Motor cycles typically have a castor angle of around 63° and trail in the region of 70mm. These values are unlikely to be ideal for a three-wheeled vehicle. Due to the large amount of trail, such a vehicle would then exhibit a strong tendency to run in a straight line, requiring constant resistance by the driver when steering. This characteristic is particularly undesirable if the overall geometry of the vehicle is slightly wrong since this will result in the vehicle forcibly veering to one side. Likewise the castor angle of a motor cycle is not ideal for a three-wheeler, because as the wheel is turned, the front of the frame drops in height and considerable effort is required to re-centralize the wheel. The castor angle of a three-wheeler is therefore usually greater than that of a two-wheeled vehicle.

Values of actual trail and castor angles, as used on commercially produced vehicles, vary depending on the type of vehicle and its required conditions of use. Three-wheeled vehicles designed to operate at low speeds on good surfaces with a high degree of manoeuvrability use castor angles approaching 90° , i.e. near vertical steering head, with a very small amount of trail. Other three-wheeled vehicles, designed for use on poor surfaces and at higher speeds, feature castor angles of around 75° with 25mm-35mm trail.

The type and condition of the tyres fitted to a vehicle have a major influence on its steering characteristics. Worn tyres will reduce the vehicle's cornering ability, especially in wet conditions. Tyre pressures also have a significant influence on cornering ability. The pressures should be increased if the vehicle is heavily laden. Experimentation with different pressures will help determine the optimum for a given vehicle.

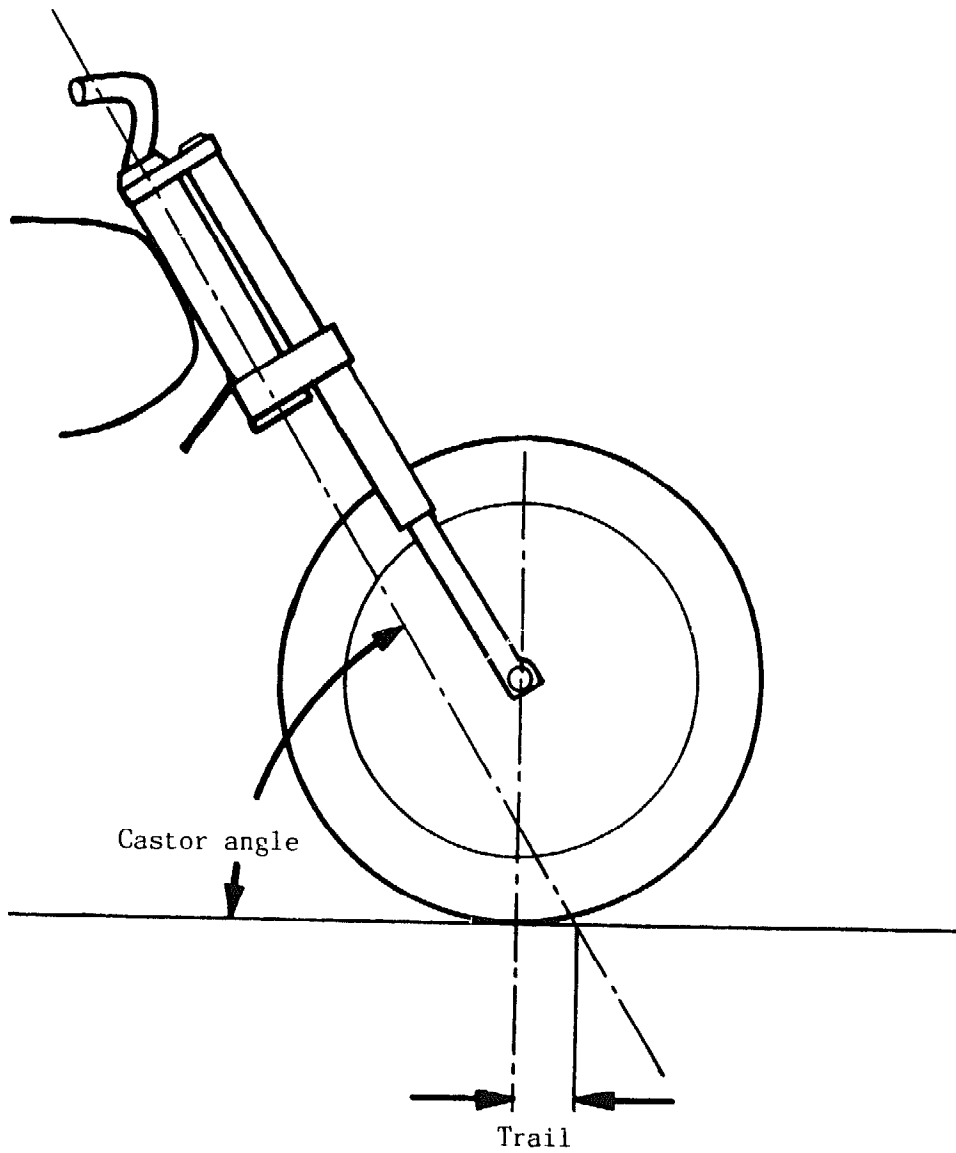


Fig. A4.1 Geometry of steered front wheel

ANNEX 5

WHEELS, TYRES AND HUBS

1. Wheels

The stresses and vibrations imposed on the wheels of a motor vehicle usually require them to be made of steel, although other alloyed metals are also sometimes used. The diameter of a wheel has a direct influence on its performance. Generally, smaller diameter wheels are stronger and are especially good at resisting side loads. Larger diameter wheels give a smoother ride and lower rolling resistance, which is especially important when going over uneven or rough ground. Larger diameter wheels also allow a higher ground clearance which is important for vehicles expected to operate over rough surfaces.

The use of suitable wheels is critical to the success of low-cost motorized vehicles. They must be of adequate strength for the application, and accept a pneumatic tyre of appropriate size. Other design considerations are:

- (i) whether the wheel is to be driven, or freewheeling;
- (ii) whether the wheel is to be supported on one side only (e.g. on a stub axle) or on both sides (as in the front fork of a motor cycle).

The manufacture of conventional steel motor vehicle wheels involves the use of expensive, precision machinery, and the investment is not worthwhile unless large-scale production of low-cost vehicles is envisaged. However, it is possible to use commercially available wheels on low-cost vehicles, or re-furbished wheels from scrap motor vehicles. Commercially available wheels suitable for low-cost motorized vehicles can be categorised into several different groups:

Motor cycle wheels Motor cycle wheels have steel rims linked to the hub with tensioned spokes. They are designed to rotate on a short, dead axle which is supported at both ends by a frame member. The standard hub is not designed to be supported on one side by a beam or stub axle. The bearings are too small for this type of mounting and therefore the stub axle would not be of sufficient diameter to withstand the stresses imposed by a load-carrying vehicle. Though fairly robust, motor cycle wheels are relatively poor at resisting side loads and therefore may not be suitable for a very heavily laden vehicle. It is important to understand that the side loads imposed on the wheels of a three- or four-wheeled vehicle are much higher than those on a two-wheeled vehicle. On the latter, side loads are minimized because the vehicle banks when cornering. The tyres and inner tubes for a motor cycle wheel are usually cheaper than those of other wheels for motorized vehicles.

In many developing country situations, vehicles using motor cycle wheels are fitted with thick section steel spokes. These make the wheels stronger. The spokes can either be of tensioned steel rods or of steel sections such as angle, flat bar or tube which are welded to the rim and fitted with a locally produced steel hub. Motor cycle wheel rims are sometimes reinforced by welding steel rods around their circumference.

Several types of low-cost motor vehicle are based on motor cycle technology and there are therefore advantages in using motor cycle wheels and tyres. In certain applications the major disadvantage of the motor cycle wheel is the difficulty of supporting it from one side only. This complicates the mounting of the rear wheels of a vehicle or the wheels of a trailer, making the use of a beam axle arrangement impractical. To facilitate this type of mounting the standard motor cycle hub can be modified. The standard bearings can be removed from the hub and one end of a beam or stub axle machined to be a tight fit in the bore of the hub, secured with a key-way and locknut arrangement. This system works only with a live axle. For the hub to be free spinning on a dead axle, hub-mounted bearings are required. It is sometimes possible to substitute bearings with a larger-than-standard internal diameter which will accommodate a bigger diameter axle. Unless the external dimensions of the substitute bearings are the same, some machining of the hub will be required to fit them.

It is also possible to produce locally a wheel of similar overall dimensions to a motor cycle wheel, and able to accept a motor cycle pneumatic tyre, but with a different type of hub to suit the method of wheel mounting and/or with greater radial and lateral strength. Figure A5.1 shows one example from the Philippines which has a pressed steel centre section welded to a standard motor cycle wheel rim, fitted with a specially made hub which fits on to a dead beam or stub axle. Another method used in the Philippines is to cast in aluminium a complete wheel, incorporating the outer casing of the hub and a rim section which accepts a standard motor cycle pneumatic tyre.

Scooter wheels Scooters, like motor cycles, are powered two-wheeled vehicles but their wheels differ in a number of respects. The scooter wheel is of significantly smaller diameter than a motor cycle wheel and is wider. The wheel is usually constructed from pressed steel with the rim made in two pieces bolted together. This simplifies the removal and fitting of tyres. Scooter wheels are often mounted on a stub axle which means that, unlike motor cycle wheels, they are supported from only one side. The small diameter of a scooter wheel gives it considerable strength but relatively poor performance on certain types of uneven terrain, which makes the use of an effective suspension system particularly important. Vehicles using scooter wheels tend to have a low ground clearance which may preclude their use on deeply rutted routes. Wheels and hubs based on the scooter design are successfully used on a number of commercially produced three-wheeled vehicles.

Motor car wheels With few exceptions, standard motor car wheels are fabricated from pressed and welded steel discs. They are of airtight construction and can therefore accommodate tubeless tyres. These wheels are very robust and, when used in conjunction with hub assemblies from motor cars, are easily adapted to certain types of low-cost motorised vehicle with a relatively large load capacity.

Truck wheels These are similar to car wheels except that they are usually much larger and can withstand substantially higher loads. They are generally too large for the vehicles featured in this publication, although they may be suitable for larger versions of the four-wheeled vehicle described in Chapter 5.

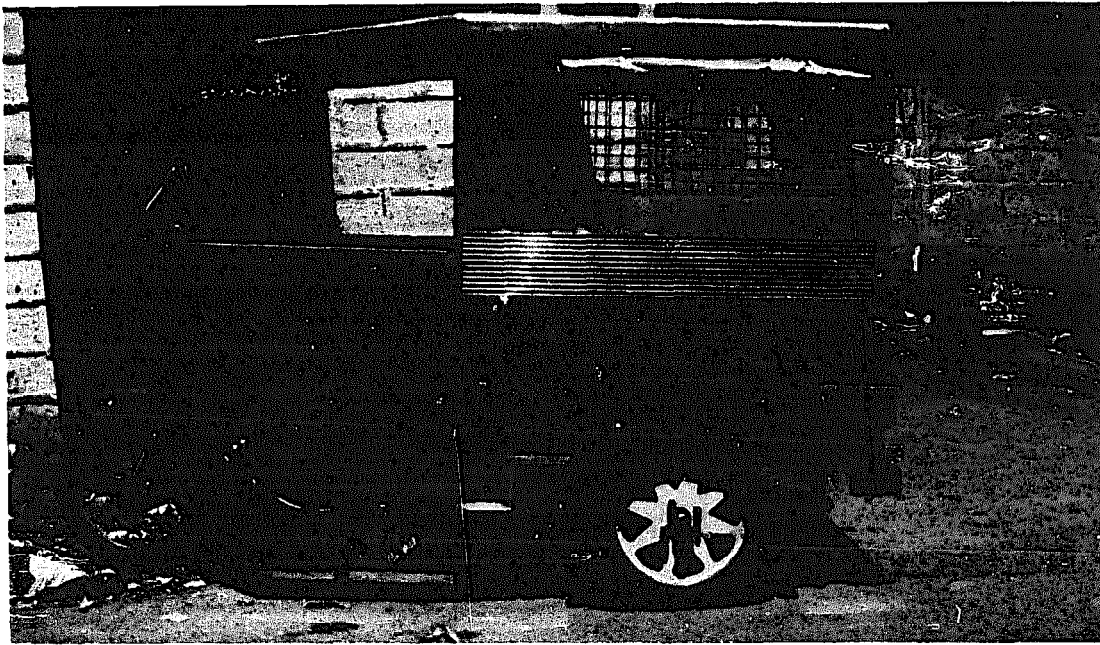


Fig. A5.1 Motor cycle based four-wheeled conversion with fabricated steel rear wheels

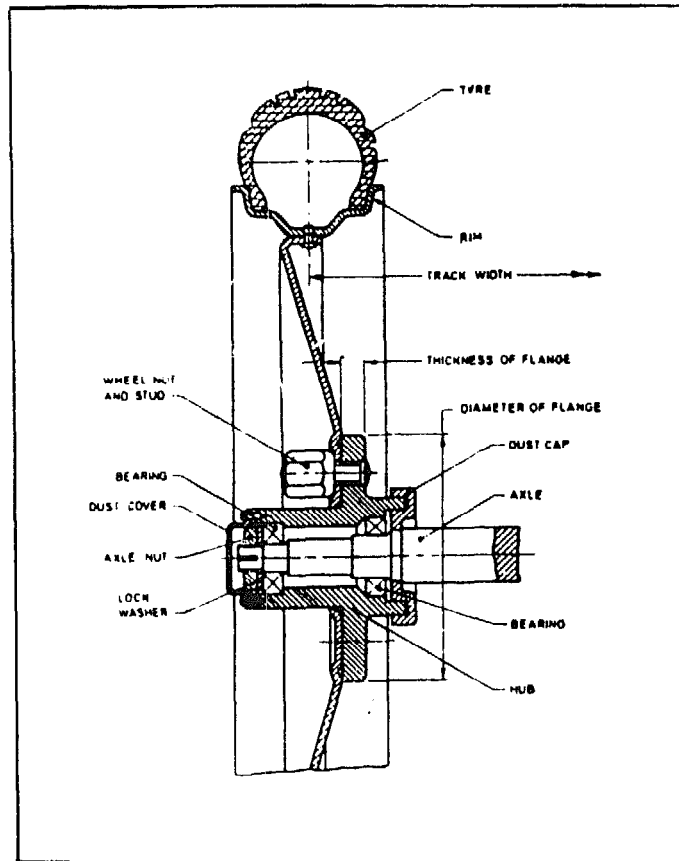


Fig. A5.2 Cross-section of typical wheel/hub assembly

Small tractor wheels Single-axle tractors (power-tillers) are available in many developing countries. Their wheels are usually made from pressed steel and are similar in size to motor car wheels. They are designed to be fitted with special tractor tyres featuring a coarse tread pattern which is ideal for very muddy conditions but, if used for the front wheels of a vehicle, results in poor steering characteristics on metalled roads.

2. Tyres

Pneumatic tyres reduce the jarring impact of shocks to the vehicle arising from the road surface. Pneumatic tyres give a high degree of traction on a wide variety of different terrain and this contributes to good vehicle stability. Pneumatic tyres are also very durable and give good wear characteristics. One disadvantage of pneumatic tyres is that they are prone to puncture. However, a variety of methods are now available to reduce the occurrence of punctures¹. In most circumstances it is necessary to use pneumatic, rather than solid rubber, tyres on low-cost motorised vehicles in order to ensure adequate performance and safety. The design of the wheels is therefore influenced by the tyre sizes that are readily available.

The use of worn tyres is not advisable since it increases the likelihood of sustaining a puncture and can also greatly reduce the control and stability of the vehicle, especially in wet conditions. It also increases the chances of the tyre bursting which, if it occurs at speed, is very dangerous. Many developing countries have facilities for re-treading worn tyres - a process known as **re-capping**. This is common practice for tyres used on conventional motor vehicles, but it is also feasible to re-cap worn motor vehicle tyres specifically for use on low-cost motorized vehicles. Coarse patterned tread can be moulded on to the tyres to improve traction in deep mud, for example. Motor cycle and scooter tyres are designed to give grip at large angles of lean and are therefore of rounded section. It is feasible to re-cap these tyres with a squarer section tread to maximize the tyre contact area with the road when used on a three-wheeled vehicle or trailer.

The inflation pressure of pneumatic tyres has a strong influence on vehicle performance. Some experimentation may be required to determine the optimum pressures for a particular vehicle. Generally, tyre pressures should be increased when a vehicle is heavily laden. Reducing the tyre pressure will improve the traction on slippery surfaces and reduce the rolling resistance on soft terrain by helping to spread the load over a wider tyre contact area. However, under-inflation of the tyres, as well as adversely affecting vehicle stability, will result in increased wear and degradation of the tyre structure due to excessive flexing of the side walls.

3. Hubs

Hubs are used on all low-cost motor vehicles to provide a secure mounting for each wheel on its axle, and to allow the wheel to rotate freely. The

¹ See, for example: Michael Ayre and Alan Smith: **Puncture prevention techniques for low-cost vehicles**. (London, Intermediate Technology Publications Ltd, 1987.

hub may be an integral part of the wheel (e.g. on a motor cycle), or a separate assembly to which the wheel is bolted (e.g. on a motor car). On a very simple vehicle, such as a trailer, the hub assembly may be the most complex part of the device. Motorized vehicles require hubs that are each fitted with a pair of tapered roller or angular contact bearings which allow the wheel to rotate freely and to support the radial and side loads imposed on the wheel. Figure A5.2 shows a typical arrangement of a hub and wheel assembly, incorporating tapered roller bearings, designed for low-speed vehicles.

It is possible to produce hub assemblies locally, as long as suitable bearings can be obtained, using standard machining, foundry, and fabrication methods.

Hub assemblies, and complete axle/hub assemblies, are available from a number of commercial manufacturers for low-speed vehicles - typically with a maximum design speed of 25-30km/h. Some of these manufacturers and details of their product ranges are listed in Chapter 8. Figure A5.3 shows exploded diagrams of two axle and hub sets offered by a manufacturer - the second set shown is equipped with brakes.

It is also possible to use hubs taken from scrap motor cars and trucks on low-cost motorized vehicles. These hubs are precision made, allowing the bearings to be easily replaced if required, and often have integral drum brake assemblies which can be adapted for use:

1. A non-driven rear beam axle using motor car wheels can be a complete motor car rear axle assembly, which has integral hubs. Alternatively, it can be a fabricated axle using a length of steel hollow section with the stub axles from motor car hubs electrically welded on either end (Figure A5.4). A jig is required to align the hubs perpendicular to the axle. Such a device is shown in use in Figure A5.5. The quality of the weld securing the hub to the axle is critical. A powerful welding set is required and if the hub design necessitates welding the steel axle to cast iron portions of the hub, special welding rods that can weld either steel or cast iron should be used. The wheel bearings and grease seals within the hub are best removed during welding to prevent heat damage. This technique of constructing beam axles is **only** suitable for low-speed vehicles.

2. For a driven rear beam axle, either a complete motor car rear axle assembly, which has integral hubs, or a fabricated live axle can be used.

The hub supporting a non-driven front wheel of a low-cost vehicle can also be adapted from a motor car hub. However, some three-wheeled vehicles use a similar hub system to that of a motor cycle using forks which support the hub from both sides. This type of configuration places less strain on the steering head but does require a fabricated axle and hub assembly.

A driven single wheel, such as is used on a front-wheel-drive, three-wheeled vehicle, requires a hub assembly which can accept the high loads imposed by the final drive chain. The final drive sprocket can be attached directly to the wheel which then rotates on a dead axle, or it can be mounted on to a short live axle (see Figures 4.15 and 4.16 in the main text).

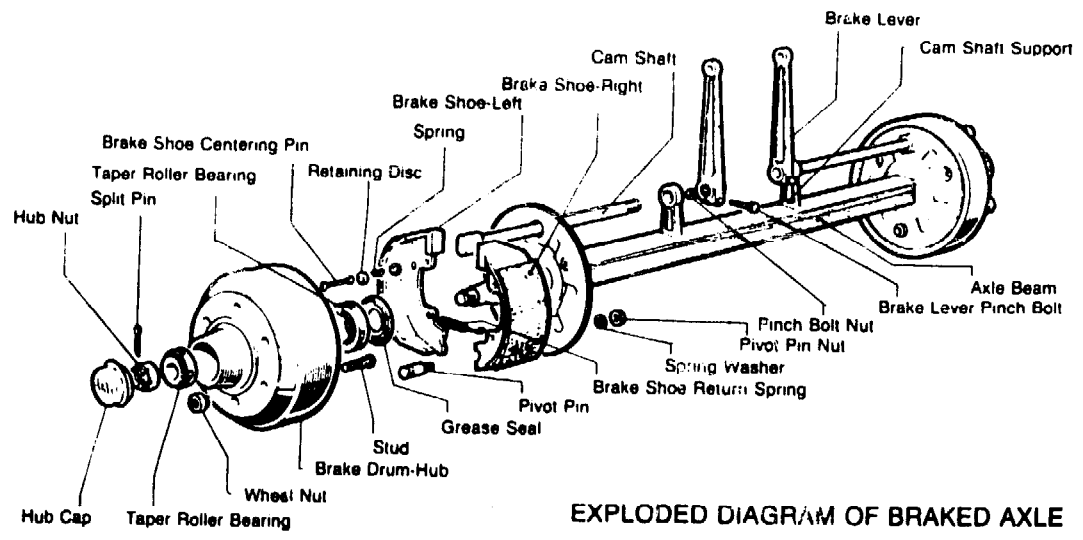
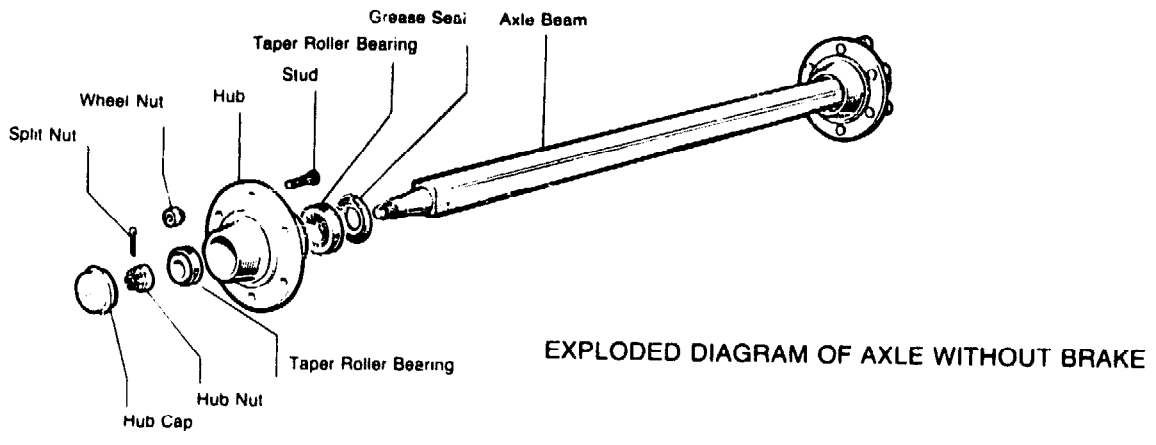


Fig. A5.3 Proprietary beam axle assemblies

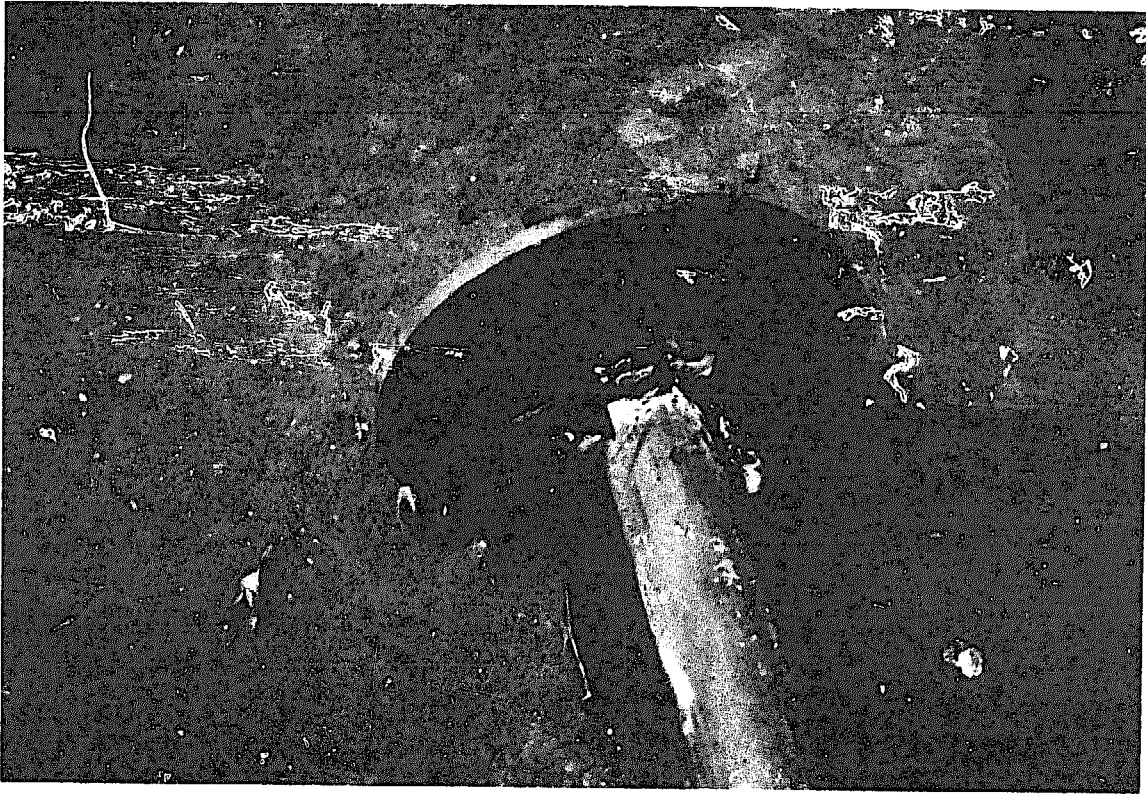


Fig. A5.4 Front wheel hub welded on to fabricated beam axle

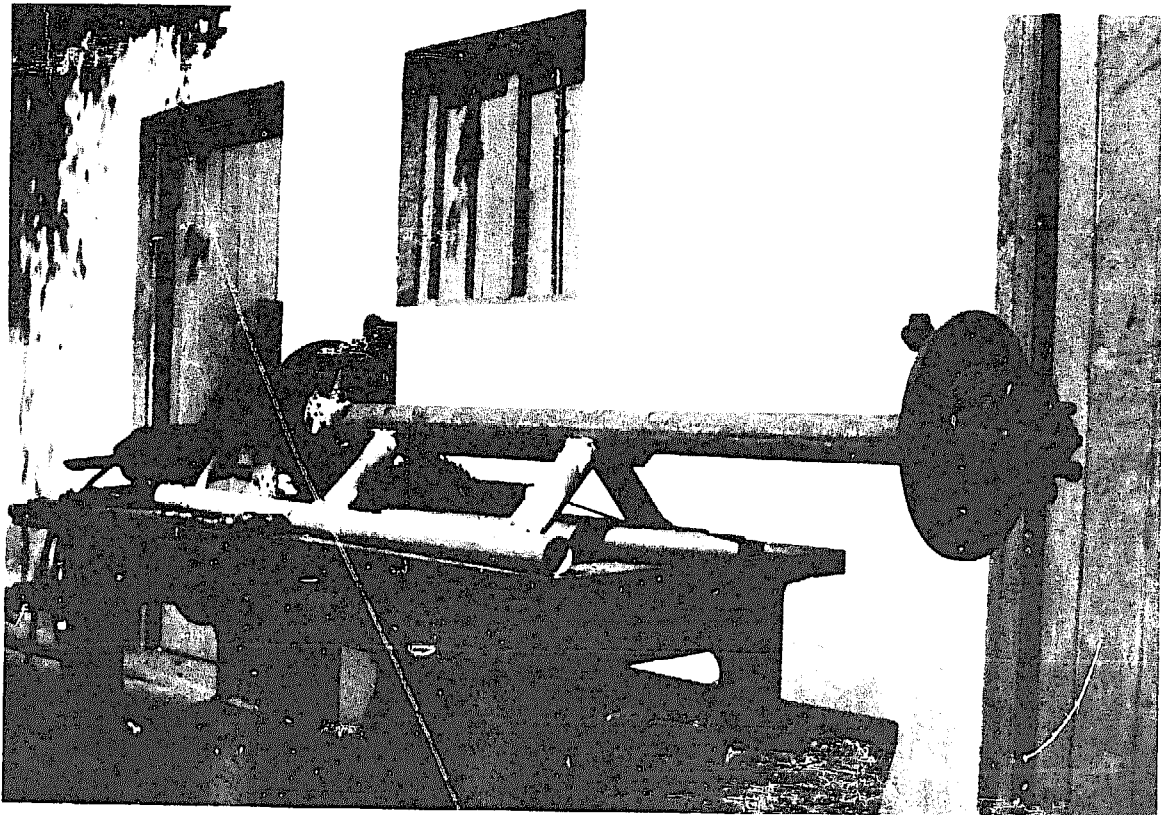


Fig. A5.5 Hub aligning jig for fabrication of axle

BRAKING SYSTEMS

1. Introduction

Brakes are used to slow down or stop a vehicle, usually by checking the rotation of some or all of the wheels. Most types of brake depend on friction for their operation. These brakes translate the energy of motion into heat energy. Friction brakes can therefore generate very high temperatures and this can adversely affect their operation, for example when controlling a vehicle's descent of a steep hill with a full load. It is therefore important to ensure, in the overall design of a vehicle, that an adequate flow of cooling air reaches the brakes when the vehicle is in motion.

Brakes normally employ a hard metallic surface, such as cast iron, for one surface. The other contacting surface is a replaceable lining or facing made of softer material with a high coefficient of friction. Asbestos is recognized as the most suitable friction material for most commercially built brake systems, the fibres being moulded or woven densely in a resin matrix, sometimes with inclusions of copper, zinc or aluminium to improve high-temperature stability. The dust from asbestos brake linings is injurious to health if inhaled.

There are four types of friction brake suitable for use on a low-cost motorized vehicle:

- drum brake;
- disc brake;
- band brake;
- block brake.

Until recent years, most commercially produced motor vehicles and motor cycles used drum brakes. However, in recent years disc brakes have come into widespread use on the front wheels of saloon cars and light commercial vehicles. Disc brakes are now also used on some motor cycles, usually the more expensive, higher-powered models. A drum or disc brake is usually integral with the wheel hub.

Brakes are operated by a **hydraulic** or **mechanical** system. Hydraulically operated brakes are used on almost all motor cars and conventional commercial vehicles. The brakes on all of the wheels are actuated by a single foot pedal. The manufacture of hydraulic systems requires great precision, and production equipment that is not likely to be available in most developing country workshops. However, many workshops have the capacity to **repair** and **maintain** motor car hydraulic brake assemblies.

For low-speed or lightweight motor vehicles a mechanical system, where the brakes are operated through rods or tension cables, is usually adequate - this remains the most common operating system for motor cycle brakes. Mechanical systems become very complex if all three or four wheel brakes on a vehicle are actuated by a single control. It is more common to have separate controls (either a hand lever or a foot pedal) for the front and rear wheel brakes.

Figure A6.1 shows schematically the layout of a typical modern motor car braking system. The system is hydraulically operated, with disc brakes on the front wheels and drum brakes on the rear.

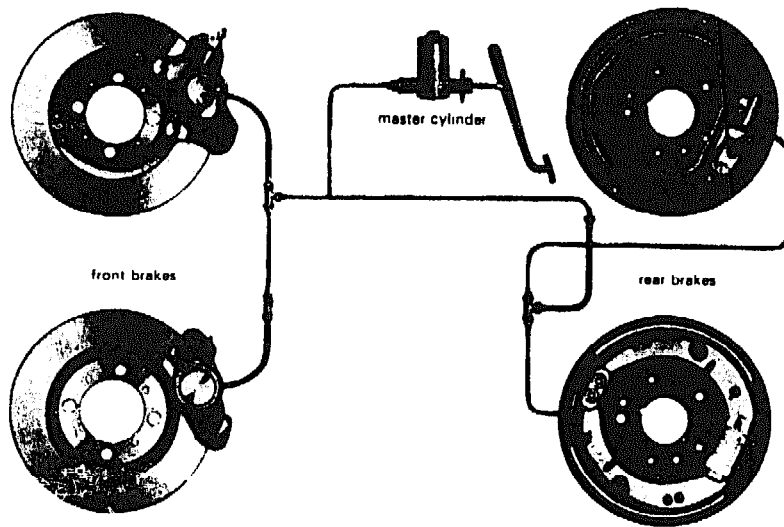


Fig. A6.1 Schematic layout of typical motor car hydraulic braking system

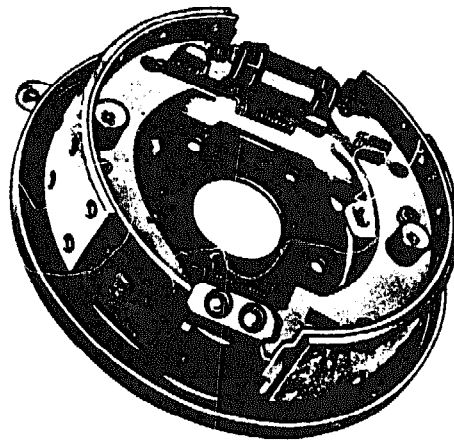


Fig. A6.2
Drum brake with
single hydraulic
wheel cylinder

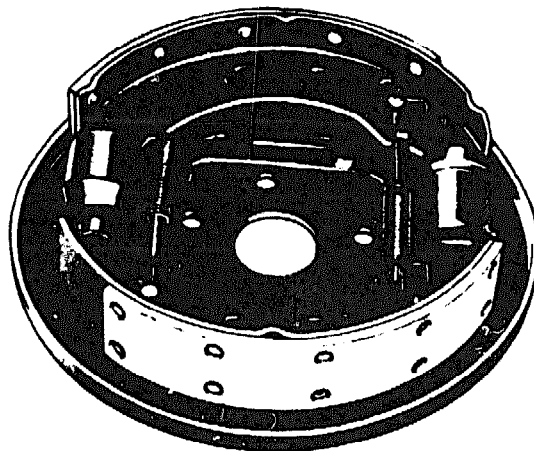


Fig. A6.3
Drum brake with
two hydraulic
wheel cylinders

2. Drum brake

Drum brakes, sometimes called internal brakes, operate by the brake shoes being brought into contact with the inside of a cylindrical brake drum by means of an expanding mechanism. The expanding mechanism consists of either:

- (i) one or two hydraulic cylinders (Figures A6.2 and A6.3), the system used on most motor car drum brakes; or
- (ii) a cable- or rod-operated cam (Figure A6.4 and see also Figure A5.3), the system used on trailers and small motor cycle drum brakes.

The rear wheel drum brakes of a motor car usually feature a cable-operated mechanism, in addition to the main hydraulic system, which operates the parking brake (see below).

The construction of efficient drum brake assemblies is likely to be beyond the capacity of a small-scale manufacturer. However, if motor car hubs are available with complete brake assemblies then these can be adapted for use on a low-cost vehicle. Brake shoes can usually be re-lined with asbestos material and other drum brake components can often be refurbished.

3. Disc brake

Brakes using a flat disc as the friction surface are called disc brakes. When the brake is actuated, the faces of the disc are clamped between fairly small pads of friction material carried by a robust caliper. Disc brakes are almost always hydraulically operated.

The production of disc brakes is quite complicated and the most likely way of using them on low-cost vehicles is to adapt assemblies removed from scrap motor cars. However, it will usually be more convenient to use drum rather than disc brakes.

4. Band Brake

A simple band brake is shown in Figure A6.5 in which the band is tightened around the rotating drum by means of the force on the operating lever. The direction of rotation shown will give a higher braking efficiency than if reversed.

The band may be made of leather, canvas impregnated with rubber, or of flexible steel lined with friction material. The drum is often made of cast iron, although aluminium or hard wood can be used for a low-cost, low-speed vehicle.

A band brake can be attached directly to the side of a wheel or mounted on a driven axle. The brake is best positioned close to a bearing because the actuating force will tend to bend the axle. Mechanical cable or rod linkages can be used to operate the brake.

Band brakes are simple and can easily be fabricated by a workshop equipped with a lathe machine. They are not as efficient as either drum or disc brakes, but can give good performance on low-cost vehicles providing they are well matched to the vehicle requirements. In general, for best results the width of the band should be made approximately one-seventh of the brake drum diameter.

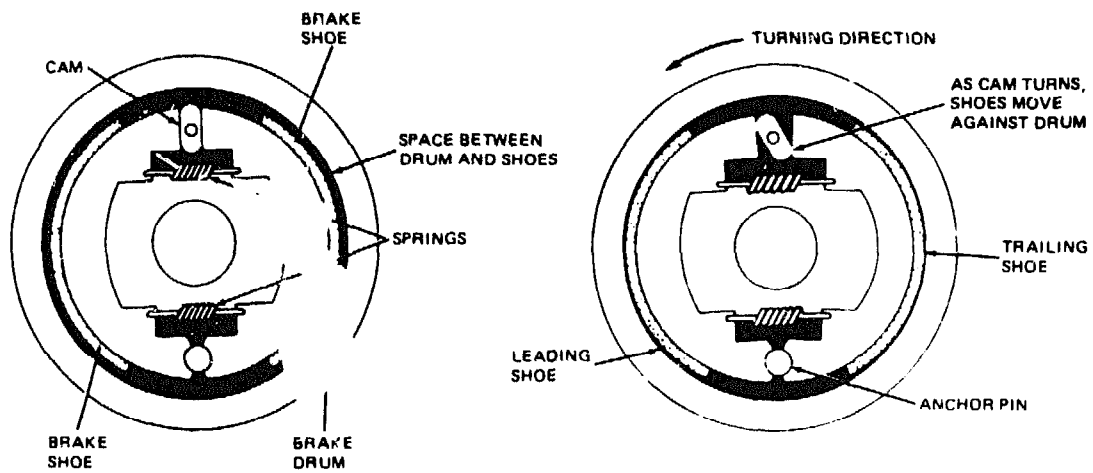


Fig. A6.4 Operation of mechanical cam actuated drum brake

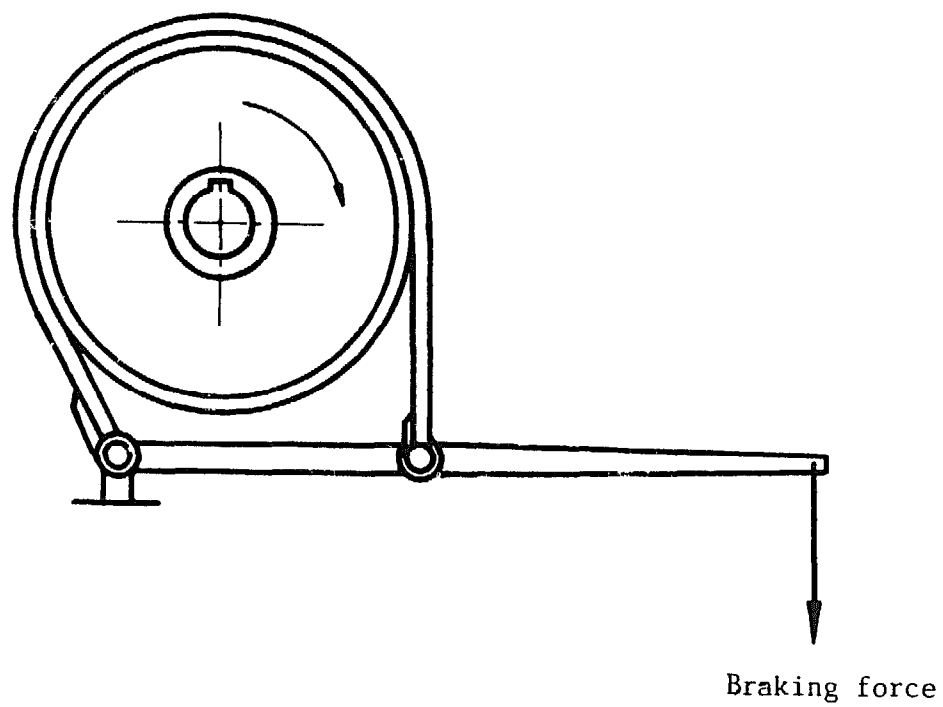


Fig. A6.5 Band brake

5. Block brake

The simplest form of brake is the block brake. An example of a block brake is shown in Figure 6.1 of the main text. A block is forced against a wheel by means of a lever. The wear usually takes place mainly on the block or the lining attached to the block. As wear occurs, the block or lining will retain the cylindrical shape of the wheel.

In Figure A6.6, if the braked wheel is rotating clockwise then the force (F) required to operate the brake will be reduced as the distance (a) is increased. This brake is called self energizing. This may be considered an advantage, but if distance (a) is too great the brake may grab and result in uncontrolled braking. If the pivot point is located at O in Figure A6.6, the self-energizing feature will be present for anti-clockwise rotation.

A block brake can be attached directly to the side of a wheel or mounted on a driven axle. The brake is best positioned close to a bearing because the actuating force will tend to bend the axle. Mechanical cable or rod linkages can be used to operate the brake.

A crude form of block brake, but one which is very cheap to produce and easy to maintain, is a device that forces a block on to the tread of the tyre. The block itself is often faced with rubber material cut from a scrap tyre. This type of brake is only suitable for low-speed use. Its performance is adversely affected by the presence of water or mud on the tyre tread and it has the disadvantage of tending to wear out the tyres.

6. Parking brake

A requirement of all load-carrying vehicles is some provision for restraining the vehicle while it is parked. This is especially important if the vehicle is parked on a gradient. It is usually accomplished by locking one or more of the wheels using a brake. Such a device is called a **handbrake** when featured on motor cars, and is then either a cable- or rod-operated system which actuates brake shoes at the rear wheels. The hand-operated lever pivots on a ratchet mechanism which maintains the applied tension on the actuating cable. A vehicle which uses adapted motor car rear wheel hubs and brakes will obviously benefit from the fitting of the original handbrake assembly.

Both band and block brakes can be used as parking brakes by including a simple mechanism for maintaining the brake actuating force.

7. Balancing of braking force

On most vehicles, brakes are fitted to all wheels and so provision must be made to equalize the braking force between the wheels to avoid skidding. In a hydraulic system, this is automatic. Motor cycles usually have separate braking systems for front and rear wheels and, unless a hydraulic system is used to link all the brakes, this is also most appropriate for other low-cost vehicles. A vehicle with two rear wheels and cable- or rod-operated brakes needs a linkage to balance the actuating force equally between the two rear wheels. This can be done (Figure A6.7) with a simple beam which is connected at each end to the brakes and which has the braking force applied at its centre by the hand lever or foot pedal.

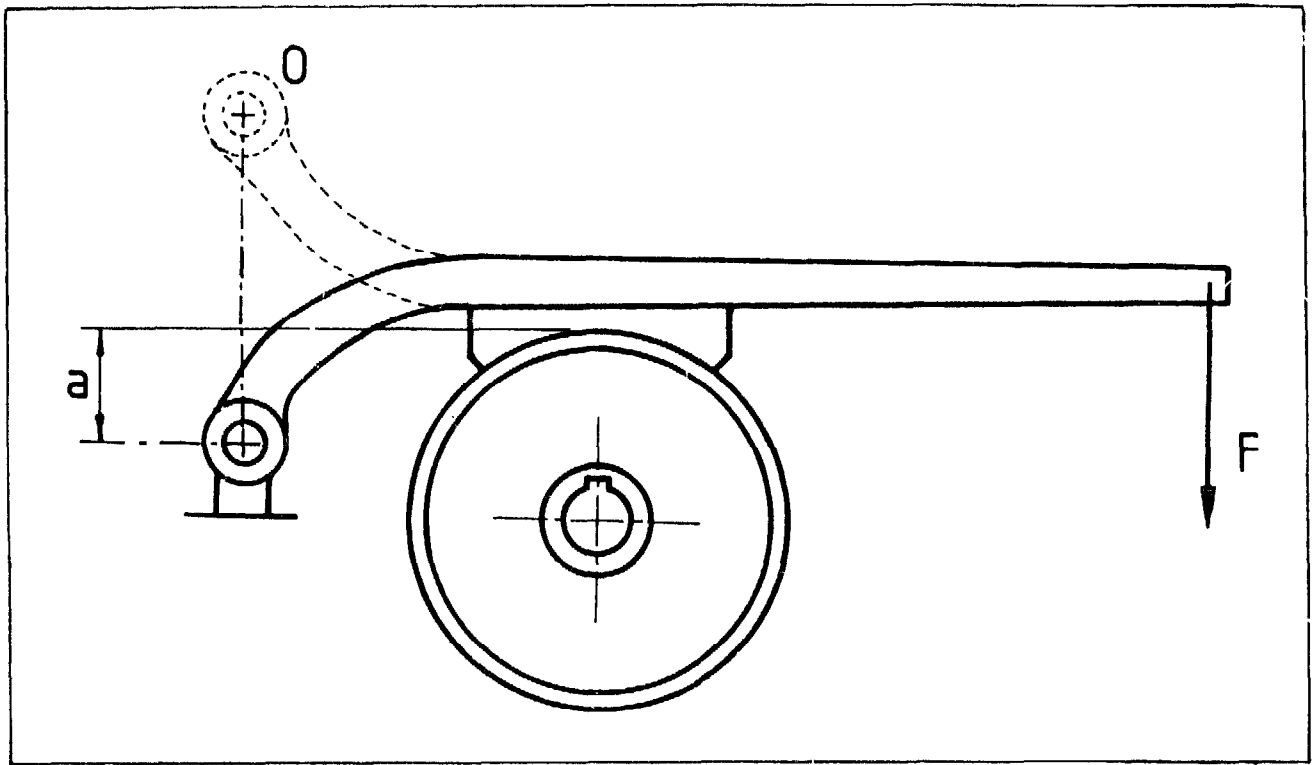


Fig. A6.6 Block brake

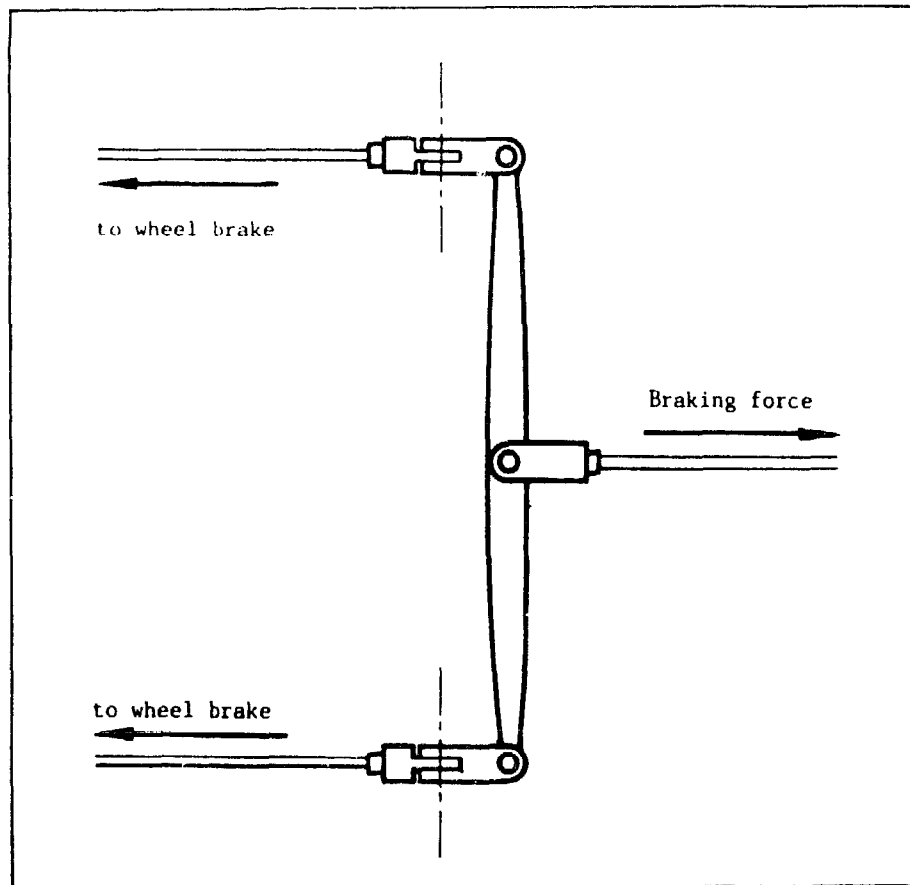


Fig. A6.7 Brake balance bar