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Automobile—An Introduction

The Automobile and its development. General classification of Vehicles. Types of Automotive Vehicles. Layout of an Automobile. Air Cushioned Vehicles and off Road Vehicles. Functions of the Main Components and Assemblies. Specifying an automobile. Resistance to the Motion of a Vehicle. Power Required for Propulsion. Acceleration and Hills Climbing.

1·1. The Automobile and its Development

Present is the age of Automobiles or Self-propelled Vehicles. A vehicle producing power within itself for its propulsion is known as a self-propelled vehicle *e.g.*, moped, scooter, motorcycle, car, jeep, tractor, bus, truck, locomotive, motor boat, ship, aeroplanes, helicopter, rocket, etc.

A self-propelled vehicle used for transportation of goods and passengers on the ground is called an automobile. Automobiles or Automotive means a vehicle which can move by itself. It differs from aeronautical vehicles like aeroplanes, helicopter, rocket etc. which fly in air as well as from marine vehicle like ship, motor boat which sail in water.

An automobile is also known as 'Automotive', 'Auto', 'Autocar', 'Autobuggy', 'Car', 'Motor', 'Motor Car', 'Motor Vehicles', 'Motor Coach', 'Motor Wagon', 'Horseless Carriage'.

In general, modern motor vehicle is a complex piece of machinery necessitating a careful attention to make it perform in a safe, economical and efficient manner. The automobile is essentially a transportation equipment unit. It is made up of a frame supporting the body and certain power-developing and transmiting units. These are further supported by tyres and wheels through the springs and axles. The engine supplies the power. It is delivered by the transmission system and rear axles through the clutch or fluid coupling to the rear wheels. The automobile is propelled through the friction of the contact between the road and the wheels. The various units are held together in proper arrangement on the frame. The protection and comfort is provided by the body of the vehicle. The essential features of the automobile (car) are shown in Fig. 1·1.

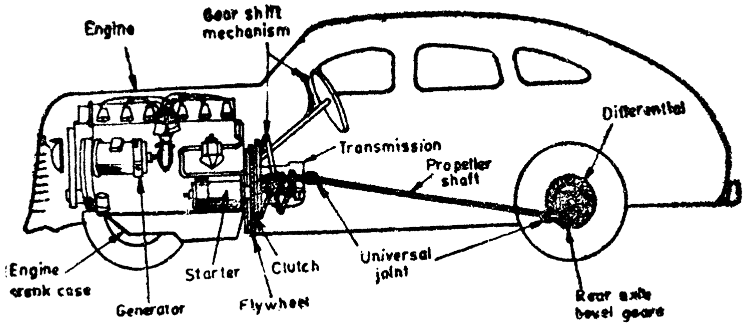

Fig. 1·1. Essential features of a car.

The means of transport provided by nature to man is severely limited in regards to the load he could carry and the distances he could carry them as well as the speed of travel with or without a load. Moreover, the physical exertion involved was not to his liking. Initially, the man tamed and trained certain animals for carrying heavier loads to greater distances at speeds higher than the man could attain. These means of transport were also limited with regard to the load carried and the speed as well as distances travelled and the physical exertion involved. Automobile has found an important place in everywhere of our commercial and social existence. Many problems relative to traffic, highways and maintenance.

"Germany is the birth place of automobile. It was invented there. It went through its first paces there and it was developed there to a high level of technical maturity. The list of German automobile pioneers is a long one starting with Nicholas Cugnot, August, Otto, Carl Benz, Gottlieb, Daimler, Wilhelm Maybach and Rudolf Diesel and going all the way upto Ferdinand Posche and Felix Wankel." (From Scala International.)

Captain Nicholas Cugnot, a Frenchman is considered to be the father of 'The Automobile'. He built the first self-propelled road vehicle in 1769-70. It had a three wheeled coach. It was fitted with a steam engine. It attained a speed of about 2½ miles per hour only for a period of 15 minutes. In 1802, the first practical steam automobile was built by Richard Trevitluck of England using a crankshaft for the first time. In 1821 Julis Griffiths of England built the first comfortable steam vehicle. The automobile propelled by gas engine was built in 1863. It was invented by the French inventor Lenoir. He drove it for about six miles. This automobile had a one cylinder engine using lighting gas. During the next few years a large amount of experimental work was carried out on both the engines and carriages.

Belgium inventor Eienne Lenoir in 1860 was the first who gave us the first practical example of internal combustion engine.

In 1876, Otto and Langen in Germany also invented and designed an internal combustion engine. But the actual development of the modern automobile dates back to 1885. Gottlieb Daimler in Germany patented an internal combustion engine in 1885-86 and installed this engine in a bicycle. The two wheeled vehicle ran on liquid fuel similar to gasoline. In 1886, Carl Benz also of Germany built a three wheeled carriage or Tricycle propelled by an interna combustion engine working on Otto cycle. It attained a speed of 10 miles per hour and produced 8 H.P. Daimler's engine is considered as the first high-speed light construction gas engine capable of running at 800 to 1000 r.p.m. In the history of automobiles this development was considered as a greatest achievement.

French firm of Daimler and Panhard was the pioneer in the manufacture of automobiles. Their automobile had a engine in front, a transmission and drive chain that carried the power to the rear wheels from front. But it was Panhard and Levassor in France who developed a car incorporating the main features of present-day automobiles in 1895. It also had the engine in front of the chassis hooked upto a sliding gear transmission. It also had a brake pedal clutch and accelerator. In America, Charles E. Duryea and Frank Duryea, both brothers produced the first Gasoline automobile in 1893 in Massachutes. It was known as the "horseless buggy". The other famous inventors and manufacturers like Henry Ford, Ranson Olds, Alexander Winston and Charles King had also built their automobiles successfully by 1896.

In was not before 1900 that the improved design of automobiles fully awakened the public to the greater utilities of this new form of transportation. During 1900-1906, the production and sales of these vehicles became a real business. In America alone, there were 121 car manufacturers with Chrysler, Nash, Hudson, Studebaker, Olds, White, Ford, Cadillac, Buick as the most noted automobiles. These were the years of production for automobiles during which the various design ideas tested, refined, improved or discarded by succeeding generations of engineers were put into motor-vehicle use. The various great names had already started appearing around which this largest industry of the world was to be built. Packard, Oldsmobile, Overland, Ford, Cadillac, Buick, White, Autocar, Pierce-Arrow, Locomotive, Locomobile, Maxwell, Franklin and Peerless had their names on automobiles before 1905.

The years that followed 1906 to 1920 are considered the era of mass production and interchangeability methods permitting lower price production. Before this the most of the automobile parts were made and fitted with hand. They were different for different machines. It was a costly and lengthy process since a worn out part was replaced by new one made by hand. The new ideas of interchangeability created history. The various parts for particular type of automobile were made as nearly identical as possible. Screws, nuts, washers etc. were all standardised. This not only improved the production assembly of the automobiles but also minimised cost of repair and replacement of worn out parts. Henry Ford was the pioneer in utilizing and improving these methods of production further.

With the year 1920 began the period of gradual change and refinement in the automobile design. The spark ignition gasoline engine was power plant of motor vehicle. The engine made was compact, light, high speed, perfectly balanced and free from vibrations, streamlined, air or water cooled, noiseless and capable of running on different fuels. The steam and electric engines were already discarded. The engines were located in the front of the chassis. The sliding gear transmission and poppet valve had established their utility for every engine design. Water cooled engines had established their universality. The main idea in the designer's mind has established to create a vehicle running under all conditions of weather and time, increasingly comfortable and easy to operate. The main changes had been the increased tyre life, replacement of rigid front axle with independent front-wheel suspension, four-wheel hydraulic brakes, increased engine compression ratios and use of stronger and cheaper new materials. Modern vehicle has stress on pollution and noise free power plant. Further research and development efforts are centred to produce a cheaper, better safer and computer controlled driverless vehicles.

In India, the first motor car appeared in 1938 with taxi cabs in Bombay. Before partition some assembly plants were only established at Bombay, Calcutta and Madras by leading foreign manufacturers. In order to create and manufacture indigenous products, two Indian factories. The Premier Automobiles Ltd., Bombay and Hindustan motors Ltd., Calcutta in 1943 and 1944 respectively were set up. The main purpose of their set-up was the progressive manufacture instead of assembly from imported components. On recommendation of the Tariff Commissions, Government of India discouraged the activities of assemblers to ensure economic output of the automobiles in 1953 and provided a further protection to the industry in 1956 with priority for manufacture of commercial vehicles, expansion of capacity of existing units and increased production of diesel vehicles.

The Maharastra and Tamil Nadu are the major states where most of the automobile and ancillary manufacturing units are located. The statewise number of manufacturers of automobiles including tractors, and two-cum-three wheelers and ancillaries are classified below :

The Indian automobile industry with a capital investment of Rs. 2,520 millions excluding Rs. 600 millions in ancillary and Rs. 1000 millions in automobile dealer-network and spare parts trade has about 25 million people employed.

Table 1·1

Type of units \ States	Maharastra	Tamil Nadu	Andhra Pradesh	Bihar	Gujarat	Haryana	Madhya Pradesh	Mysore	Punjab	West Bengal	Delhi	Rajasthan
Automobile Vehicles	6	4	1	1	1	2	1	1	1	1	—	—1
Ancillaries	60	33	3	—	7	9	1	7	5	10	24	1

Production of Automobiles

The ranking of India in the world market can be seen from Table 1·2.

Indian automobile industry had exported automobile vehicles and ancillaries during the years 1970-71, 1971-72 and 1972-73 foı Rs. 209, Rs. 119·7 and Rs. 128·8 millions respectively.

At present almost all vehicles produced in the country are 98 per cent indigenous and only 2 per cent imported. There are two types of automobile vehicles manufactured in India— (1) Defence Vehicles (2) Civil Vehicles.

Defence vehicles like Shaktiman trucks, Nissan 1 tonne trucks and Nissan (Jonga) Jeep are being manufactured by the defence establishments in the vehicle factory at Jabalpur. This factory established in 1969 is manufacturing Shaktiman 3 tonne trucks through an agreement with M.A.N. of Germany at 6000 trucks per annum and Nissan trucks and Nissan Petrol vehicles (Jeep) at the rate of 200 and 100 per month respectively.

For civil automobile vehicles, there are seven approved manufacturers of automobiles, one manufacturer of engines and twelve manufacturer of motor cycles, scooters, three wheelers, moped etc. These are described as under :

(A) Automobiles Manufacturers

1. Hindustan Motors Ltd., Uttarpara, Calcutta—Hindustan Ambassador cars, Bedford, Hindustan trucks and buses in the range of 1 to $7\frac{1}{2}$ tonnes, goods chassis (3 tonnes, 5 tonnes, $7\frac{1}{2}$ tonnes) diesel.

Premier Automobiles Ltd., Bombay—Premier President, Premier Padmini, Premier Pioneer and Premier Roadmaster cars, Dodge and Forgo trucks as well as buses in the range of 1 to $7\frac{1}{2}$ tonnes, goods chassis (P_4, P_6—5 tonnes, $7\frac{1}{2}$ tonnes) Diesel and Patrol.

Table 1·2

Country	*Type of vehicles*	*Monthly average*		*Increase over 1961 (% age)*
		1961	*1971*	
U.S.A	A*	462·0	72	55·8
	B*	94	171·0	81·9
Japan	A	20·8	309·6	1388·5
	B	65·8	175·5	166·6
West Germany	A	159·0	308·0	93·7
	B	20·3	23·1	13·8
France	A	82·3	224·5	172·8
	B	18·1	28·5	57·5
U.K.	A	83·7	145·2	73·5
	B	38·4	38·0	1·1
Italy	A	57·8	141·8	145·8
	B	5·48	9·66	76·3
India	A	2·39	4·19	70·7
	B	2·13	3·12	46·5
World	A	96·50	2,017·7	114·7
Excluding China	B	322·5	50·8	70·8

*A—Passenger cars, B—Commercial vehicles.

3. Standard Motor products of India Ltd., Madras—Standard Herald Mark III cars and standard 1 tonne trucks and Gazel cars.

4. Ashok Leyland Ltd., Madras—Leyland Comet truck and buses, Beaver Hipo and Jumbo trucks in the range of 5 to 16 tonnes.

5. Tata Engg. & Locomotive Co., Ltd., Bombay—Tata trucks and buses in the range of 5 to 9 tonnes and 3 axle 10 tonnes Dumpers.

6. Mohindra & Mohindra Ltd., Bombay—Kaiser Universal Jeeps and 3/4 tonne ; FC 150, 160 trucks, FC—2601 Truck (Diesel).

7. Bajaj Tempo Ltd., Poona—Tempo Hanseat 3-wheels and Tempo Viking and Matador 4-wheeler in the 3/4 to 1·6 tonnes range.

8. Sunrise Auto Industries Ltd., Bangalore—Badal car.

Leading Manufacturers of Motor Vehicles in the World.

1. U.S.A.
   GENERAL Motors.
   Ford—Ford Cars.
   Chrysler.
2. Japan.
   Toyota.
   Nissan.
3. West Germany
   Volkswagon.
4. Italy.
   Fiat.
5. France.
   Renault.
6. U.K.
   B.L.M.C.
   Austin/Morris BL, 1.

(B) Engine Manufacturers

1. Simpson & Co. Ltd., Madras—Perkins P_6V, $P_6/354$ and P_5/V vehicular diesel engines.
2. Carburettors Ltd., Madras.
3. Premier Automobiles Ltd., Bombay—Meadows Engines.

(C) Motorcycles, Scooters, Moped and Three Wheeler Manufacturers

1. Automobile Products of India Ltd., Bombay—Lembretta Scooters, Lamby 150 cc and 175 cc Mac. 175 and Three-wheelers.
2. Bajaj Auto Ltd., Pune—Bajaj Scooters and Three-wheelers.
3. Escort Ltd., Faridabad—Rajdoot Motor-cycles and Scooters.
4. Andhra Pradesh Scooters Ltd., Hyderabad—Allwyn Pushpak.
5. Punjab Scooters Ltd., Nabha—Vijay Kesari.
6. Enfield India Ltd., Madras—Enfield-Motorcycle 350 cc, 197 cc ; Fantabulas scooters and three-wheelers.
7. Aravalli Savachalit Vahan Ltd., Jaipur—Aravalli scooters.

8. Scooters India Ltd., Lucknow, Vijay Delux, Vijay Super.
9. Ideal Jawa (India) Pvt. Ltd., Mysore—Jawa Yezdi Motorcycles (60 cc and 250 cc).
10. Gujarat Small Industry Cars Ltd.. Ahmedabad—Girnar Scooters.
11. Mopeds India Ltd., Coimbatore—Suvega Mopeds.
12. Sound Zweirad Union (India) Pvt. Ltd., Gwalior, Vicky Mopeds.
13. Kinetic Engg. Pvt. Ltd., Pune—Luna Mopeds.
14. Karnataka Scooters Ltd., Bangalore—Falcon 150 Scooter.
15. Kirloskar Ghatge Patil, Kolhapur—Laxmi Mope s.
16. India Automobiles Ltd., Jamshedpur—Hitodi Panther Mopeds.
17. Atlas Scooter Ltd., Sonepat—Atlasolex.
18. Tamil Nadu Mopeds Ltd., Madras—Mayuram Mopeds.

(D) Tractor Manufacturers

1. Escorts Ltd., Faridabad—Escort Tractors—3036, 3350.
2. Escorts Tractor Ltd., New Delhi—Ford Tractors—3600.
3. Hindustan Tractors Ltd. Baroda—Hindustan Tractors.
4. International Tractors Co. of India Ltd., Bombay—International Tractors.
5. Eicher Tractors Ltd., Faridabad—Eicher Tractors.
6. Tractors and Farm Equipment Ltd., Massy Ferguson Tractors—ME-1035 Tractors, TAFE-504 Tractors.
7. Gujarat Tractors Cars Ltd., Baroda—Hindustan HWD-50.
8. H.M.T., Pinjore—Zetor Tractors—2511, 3511, 5711.
9. Punjab Tractors, Mohali—Swaraj Tractors—724, 735, Swaraj.
10. Kirloskar Tractors Ltd., Bombay—International B-275, B-444.
11. Pittie Tools Pvt. Ltd., Poona—Pittie Tractors.
12. Harsha Tractor Ltd., New Delhi—Harsha Tractors.

In order to test, search, develop as well as trained workers for automobile, different facilities are available at different organisations like, Central Mechanical Engineering Research Institute, Durgapur: the Indian Institute of Science; Bangalore ; National Test House, Alipur Road, Delhi and the National Metallurgical Laboratory, Jamshedpur.

The present-day model of automobiles seem to be moving houses furnished with various types of facilities. They are conver -

ble into different rooms of a modern house—dining room, drawing room, bed room, etc. Every new hour is creating new development in every phase of automobile.

The automobile industry is a fast developing industry. From the later 18th century when the first automobile was put on road, this industry has developed tremendously. Now there are thousands of factories all over the world manufacturing numerous types of automobiles. This industry employs crores of men and women directly and indirectly in allied industries. The automobile engines are also being used in engine powered machines for agriculture, construction and manufacturing processes. Various types of small engines are also being used in lawn movers, power saws, snow removers and similar equipments. The automobile industry is a developing and demanding industry which does not find its end or saturation point. There is a great demand for varied types of automotive products, vehicles and engines. There is also a great demand for trained and experienced persons in this industry for diagnosing motor vehicle troubles, repairing and replacing engines, components, transmissions, propeller shafts, differentials, axles, steering system components, brake system components, suspension components, air-conditioners, heaters, radios, body and glass work.

Automobile of future. Future of the automobiles is highly encouraging. A golden age of automobile is in store both for the driver and the consumer. An army of high technology inventions—from fluorescent dashboards to computerised gears, bonnet raindrop detectors which will automatically activate the windscreen wipers are in offring. Although the cars will be alike to look at converging on an aerodynamic ideal like a fish without fins, yet underneath the body there will be an individualised car having a network of Computer controls for heeding to the driver's instructions and for adjusting to the road conditions as well as to rescue the driver from mistake. The future motor vehicles will be less bothersome to ours, more economical to drive and more fun to drive.

An explosion is being brought in the passenger compartment amintles by the automotive electronics. The computerized rear-view mirrors will adjust automatically to day and night driving. Memory seats used would automatically assume any of the four settings preferred by the drivers. With trip computer fitted in most of the foreign cars, it is possible to monitor petrol usage and outside temperature as well as to find out how much time it will take you to reach your destination. By 1990, it is expected that with the computerised controls car might recognise owner or driver by his infra-red key and open its door adjust its climate control seat, mirrors, handling and fuel economy to suit the approaching person and start the engine.

Dramatic changes are taking place in dashboard improvement. Many luxury cars are already using microprocessor driven colour instrument panels. To indicate low fuel, fluorescent white and blue green lights with aminated seat belt warnings and a bar-chart petrol gauge turning a yellowish orange is being used in Oldsmobile. Multiplex wiring which uses a single wire or optic-fibre cable carries messages from more than one instrument will help the car-makeis to pack more controls on the steering column are being used in many cars. Ford is using such wiring to put 10 control buttons at driver's fingertips. A touch-sensitive dashboard display screen with which the driver will be able to control the radio, interior temperature and trip computer by just putting a finger to the screen is being introduced in 1986 Buick car. A specially designed map is being developed by Daimler-Benz for the driver who will refer to it and punch the co-ordinates of his destination into the computer before starting a trip. A little arrow on the dashboard will tell him the direction in which he is heading.

Super computer technology is going to transform every basic function of the car. Computer-controlled active suspensions whose rudimentary versions have already appeared on Sedans by Toyota, Nissan and Mitsubishi are the ultimate improvement in automotive handling. By pushing a button on the dashboard, provides on a Mitsubishi version, the driver can select either a hard mode or an automatic mode to let the vehicle decide whether a hard or soft ride is most appropriate for the environment. The car will automatically stiffen its suspension during hard cornering or hard braking or at high speed or will make it pillow at low speeds. By comparing the steering wheel motions and speed the computer deduces the conclusion. By pumping up and deflating air springs and varying the distributor of fluid within shock absorbers, Mitsubishi is doing the operation.

Lotus Cars Ltd., are developing a far more refined suspension system which is replacing springs and shock absorbers completely with hydraulic pistons. Road irregularities and cornering forces are being adjusted by computers. For truly exotic effects like keeping a car level through a turn instead of allowing to lean over, programmed suspensions are used.

Computers also help to exert finer control over engine functions resulting in greater efficiency. The function of opening and closing of valves is liable to taken over by tiny, powerful electromagnets from mechanical crankshafts in near future. This will reduce engine weight and complexity to help the computers to vary the timing and action of the valves and maximize engine efficiency at all speeds as evident from scientists, progress at General Motors.

Manufacturer's are also planning maintenance free car in which batteries no longer require service, transmission as well differential do not need any draining and refilling and the traditional time ups have been eliminated by electronic fuel system. General Motors and Ford Sedans are using computers to control the engines to adjust the mixture of petrol and air keeping engine efficient even if the spark plugs wear, air filters get dirty and the quality of petrol varies.

It is expected the future cars operated andcontrolled by computers will be helpful for the owner, mechanics and the driver.

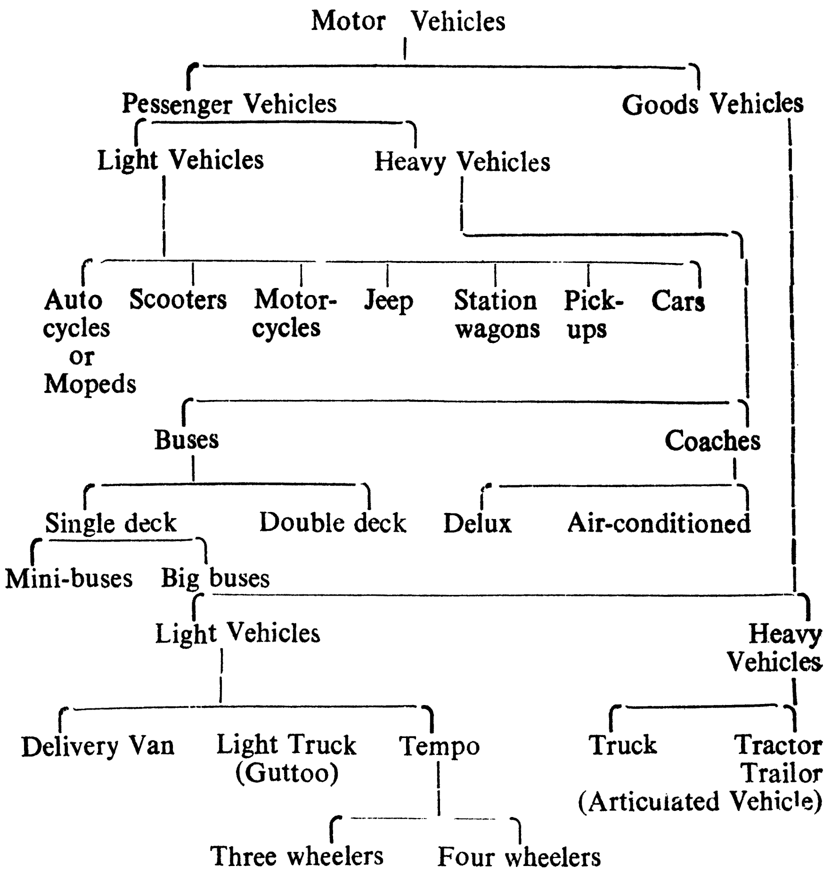

Fig. 1·2. Classification of vehicles.

1·2. General Classification of Vehicles

There are numerous types of automobiles used in the world. The various types of automobiles are classified in Fig. 1·2. There are in general three main classifications of the varions types of vehicles :

(1) The single-unit vehicles or load carriers.

(2) Articulated vehicles.

(3) The heavy tractor vehicles.

(1) **Single-unit vehicles** are of conventional four-wheel type. The great majority of vehicles are of two axle design. In these vehicles the front axle is a steering non-driving axle and the rear

axle is the driving axle. With the passage of time, a great many changes have taken place in the number of axles and the driving arrangements.

In this classification digital terms like 4×2, 4×4, 6×4 etc. are commonly used. The first figure denotes the total number of wheels and the second figure the number of driving wheels. For example, the front drive Fiat Car, 4×2 is a conventional four wheeler. For denoting a driving axle and a non-driving axle, a widely-accepted convention of *x* and *o* denotion is used. A driving axle is denoted to the letter *x* and *a*, non-driving axle by the letter *o*. A Fiat car would be classified as *xo* and *a* conventional vehicle by *ox*. In general, eight combinations as given below are used for most of the classification :

(*a*) *ox*—Conventional four wheeler.

(*b*) *xo*—Front drive four wheeler like Fiat.

(*c*) *xx*—Four wheel drive four-wheeler.

(*d*) *oox*—Six wheel drive with two steering axles.

(*e*) *oxo*—Six wheeler with trailing non-axle drive or driving on middle axle only.

(*f*) *oxx*—Conventional six-wheeler.

(*g*) *xxx*—Six wheel drive six-wheeler.

(*h*) *ooxx*—Conventional eight-wheeler with twin steering axle.

The items *oox* and *oxo* are now rarely used. These are generally used for carrying bulky loads and, therefore, require a long wheel base. For cross-country uses, vehicles like *xx* and *xxx* are used. In these vehicles, an auxiliary two-speed, gearbox is used in series with the main gear box. The arrangement made is such that when the low range of auxiliary gear box is in use, the front wheels are only driven. But the vehicle becomes *ox* or *oxx* when the high auxiliary range is in use. This auxiliary gear box is commonly called a 'transfer case'. In recent years, certain military vehicles with four-wheel drive engagable on all gears at will have been designed.

(2) Articulated vehicles with tractor units are commonly denoted by *ox* and sometimes by *oxx*. A lower powered three-wheeler with a single steering wheel in front and a conventional rear driving axle is an example of articulated vehicles. It has a greater handling ability in awkward places. It can be turned about its own tail due to the three-wheel construction. The coupling mechanism between semi-tailer and tractor in most of these vehicles is arranged for automatic connection and coupling up necessitating only its reversing into the position. But for uncoupling operation, a lever is provided within the driver's cabin to reverse the whole process. A pair of retractable wheels in front are also provided. Alongwith

the coupling or uncoupling operation, they can be raised or lowered automatically.

(3) Heavy tractor or independent tractor vehicles are generally denoted by *ox* or *oxx*. To move heavy loads, they commonly operate in pair either in tandem or as 'puller' and 'pusher'. While descending appreciable gradients, stability is provided by the latter arrangement.

A special consideration is made in respect of the drive to the front wheels in all-wheel-drive vehicles. We know that the front wheels are to travel farther than the rear wheels on every bend. The wind-up produced by this difference of travel, over-stresses the transmission system. To avoid this a great necessity of some form of differential or its equivalent has been felt to provide it the front and rear drives. It has been seen that if the conditions are not very abnormal, sufficient amount of tyre slip taking place under running conditions would release these stresses completely.

An all-wheel drive is better than the introduction of differentials between the various axles. It provides proper adhesion under the worst possible conditions. On the other hand, the drive to all the other axles is liable to be lost if any one axle or group of axles loses adhesion.

The provision of a free wheel in the front-drive system which allows the front wheels to over run is not a very desirable solution although it is complete. The provision of a special form of differential also create certain disadvantages, though it fulfils the requirements, and drives the most reluctant wheel or axle. Certain people have suggested multiple-axle vehicle, but certain special suspension problems arise in this case.

1·3. Types of Automobiles

There are numerous types of automobile found in different parts of the world. With respect to different purposes, the various types of automobiles are classified as under :

I. With respect to the use :

(*a*) Auto-cycles and Mopeds.

(*b*) Scooters and Motor cycles.

(*c*) Cars, Station Wagons and Pick-ups.

(*d*) Lorries (Buses) and Trucks.

(*e*) Tractors.

II. With respect to capacity :

(*a*) H.T.V. or Heavy Transport Vehicles or Heavy Motor Vehicles : Bus, Coaches, Truck, Tractor.

(*b*) L.T.V. or Light Transport Vehicles, or Light Motor Vehicles (Cars, Jeeps, Scooter/Motor cycles).

(*c*) Medium Vehicles : Tempo, Minibus, Station Wagon.

III. With respect to the fuel used :

(*a*) Petrol Vehicles : Jeeps, car, Scooters, Motor Cycles.

(*b*) Diesel Vehicles : Truck, Bus, Tractor, Bulldozer, Mercedes Car.

(*c*) Gas Vehicles : Coal-gas, Gas Turbine or Producer gas Vehicles.

(*d*) Electric Vehicles—using electric storage batteries or accumulators to drive electric motors attached to the front or rear wheels, *e.g.* Heavy Cranes, battery truck, Cars, Forklifts.

(*e*) Steam Vehicles, Steam roadrollers, it is now obsolete.

IV. With respect to the make :

(*a*) Layland, Tata, buses and trucks.

(*b*) Ambassador, Fiat (Premier-President), Standard, Herald etc. cars.

(*c*) Vespa/Bajaj, Lambretta, Raj Hans, Rajdoot, Royal Enfield, Vijay Delux, Vijay Kesari, Priya Scooters.

V. With respect to wheels and axles :

(*a*) Two Wheelers : Motors Cycles/Scooters.

(*b*) Three Wheelers : Tempos, Auto Rickshaws.

(*c*) Four Wheelers : Cars, Jeeps, Buses, Trucks (6 Tyres) etc. Buses and Trucks have six tyres out of which four are carried on the rear wheels for additional traction.

(*d*) 6 Axle Wheelers (10 tyres) Vehicles : Shaktiman, Dodge.

VI. With respect to the drive :

(*a*) Left hand drive—most of the American vehicles.

(*b*) Right hand drive—most of the Indian vehicles.

(*c*) Fluid drive—Vehicles using Fluid Coupling Engine and Transmission.

(*d*) Front Wheel Drive (F.W.D.)—Volks Wagon, Skoda, Austin.

(*e*) Rear Wheel Drive—most of the Indian vehicles.

(*f*) Single Wheel Drive

(*g*) Two Wheel Drive

(*h*) Four Wheel Drive

(*i*) Six Wheel Drive

(*j*) All Wheel Drive—Jeep 4×4.

VII. With respect to the motion :

(*a*) Reciprocating—Piston Engines.
(*b*) Rotary—Wankel Engine, Gas Turbine.

VIII. With respect to the suspension :

(*a*) Conventional—Leaf Spring.
(*b*) Independent—Coil, Torsion bar, Pneumatic.

IX. With respect to the body and number of doors :

(*a*) Sedan—Two doors four doors.
(*b*) Convertible—Jeep.
(*c*) Station Wagon.
(*d*) Delivery Van.

X. With respect to transmission :

(*a*) Conventional—Most of Indian vehicles.
(*b*) Semi-automatic—Modern British vehicles.
(*c*) Automatic—American vehicles.

1·4. Layout of an Automobile

The layout of different types of vehicles is different. A private car which is to carry up to eight persons is generally four seater.

The layout of a car is shown in Fig. 1·3. It shows the position of the main parts of an automobile. It consists of engine located at the front of the vehicles, followed by a clutch, gear box, propeller

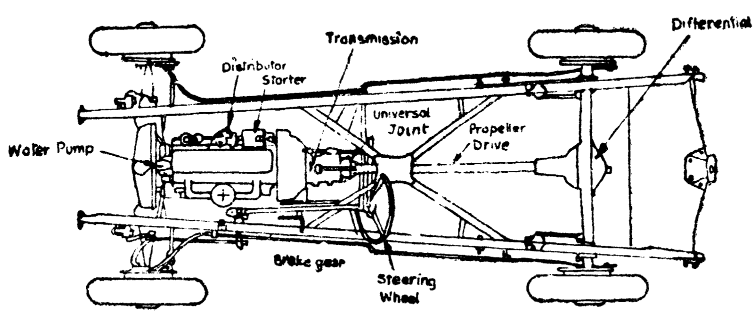

Fig. 1·3. Layout of a car.

shaft, universal joint, differential, back axle ete. The radiator is located in front of the engine. Various other parts of the vehicle shown in the layout are dynamo, horn, steering box, fan, timing gear, carburettor, air filter, gear control, steering wheel, cylinder, petrol tank, rear axle, back axle. The drive from the gear box is conveyed through a short shaft to the front universal joint of the propeller shaft. From the propeller shaft it is conveyed to the rear wheel through a sliding splined type of joint universal. The bevel gear of the short shaft is driven by the rear universal joint. This bevel gear meshes with a larger bevel gear which drives the two rear axle shafts through a differential gear.

The layout also consists of independent front-wheel springing with quarter-elliptic leaf springs, steering column bevel-gear control and hydraulic braking system.

The components of the cars and their proper location is explained as under :

(1) **Wheels.** The wheels which are four in number are fitted below the car chassis to support the load of the vehicle and passengers as well as run the ar. They are fitted with hollow rubber tyres filled with air in rubber tubes under sufficient pressure necessary for carrying the load. The shocks caused by road irregularities are absorbed by them. By fitting springs between the wheels and the vehicle allowing the vertical movement of wheels in relation to vehicle, greater part of unevenness of road surfaces is taken care of.

(2) **Front axle.** It is used for steering front wheels carried on stub axles swivelling upon king pins the axle extremities.

Steering arms and a track rod link the wo stub axles together for swivelling them by a steering wheel about the king pins. The steering wheel linked to one of the stub axle by a shaft, a gear box and a suitable linkage is operate by the driver's hand wheel. Previously the axle—a one-piece beam was used to support the vehicle through springs. An arrangement known as independent front suspension has replaced the axle and spring arrangement. Under the control of springs, the wheels are free to rise and fall vertically independently of each other.

Real axle. For fixing rear wheels, a tube like shaft enclosing driving shafts with suitable bearings for rotating the wheels in used. It is enlarged at the centre for enclosing the final-drive gears used for providing main speed reduction between the engine and the driving wheels. The change of direction of drive from the fore and aft line of the propeller shaft to the transverse line of the axle shafts is also provided by this tube known as *Real axle.*

When going round a curve, the inner wheel has to travel a smaller distance in comparison to the outer wheel. But both the rear wheel would rotate at the same speed if they are connected by a shaft. This rotation of both the wheels would result in slipping of one or both of them on the road surface causing excessive tyre wear as well as severe twisting loads on the shaft. Moreover, the two wheels of the exactly similar diameter (which is not usually so) can only turn at the same speed without lip on the straight road. Tyres fitted on the opposite sides may be of different states of wear and even tyre of same nominal diameter made be different or same manufactur may differ in ctual dimensions or may not be exactly similar. Due to change of rolling radius (the distance from the wheel centre to the ground) the effective size of the tyre may be altered by different inflation pressure also.

Each wheel is provided with its own separate half-shaft connected by a differential gear and meeting at about the centre of the axle. The wheels are free to rotate at different speeds although they are provided with equal drive by the differential gear.

For preventing the transmission of shock from uneven road surfaces to the vehicle, springs are used to support the vehicle on the axle.

In order to allow for the vertical movements of the wheels relative to the frame as well as to allow the parts of the shaft to operate at different angle, another increasingly used arrangement is used. It consists of mounting the final-drive gears and the differential gear in a casting attached to the frame with independently sprung wheels attached to them by means of shafts through devices called universal joints.

Power unit. It consists of an internal combustion engine. It is usually mounted at the front end of the car. The clutch and the gear box are placed immediately behind it. The three components—engine, clutch and gear box are assembled into a single unit.

Propeller shaft. For connecting the output shaft of the gear box to the rear, a long shaft known as propeller shaft is used. This shaft is either enclosed in a tubular casing or kept exposed or opened with a universal joint fitted at each for allowing the changes in the shaft alignment with the rise and fall of the rear axle due to road surface variations. Universal joints cannot be eliminated even if the final drive gears are fixed to the frame with the wheels springing independently. Neither the misalignment resulting from the flexing of the vehicle structure over bumpy road surfaces can be avoided nor the precise alignment of shaft can be ensured without them.

Frame. For attaching and supporting the various components of the vehicle, a metallic frame of some type is used. Previously a rectangular frame of steel pressings riveted together was used for attaching different components as well as the body. The assembled vehicle without body was called chassis. They were initially manufactured separately and assembled together. Except in case of a few cars, the manufacturing of the frame and chassis is now done together in an assembled form with the body designed as the main structure of the vehicle capable of carrying the loads. In comparison to previous arrangement consisting of separate chassis and body ; the modern trend of combined construction known as chassisless unitary construction is lighter and stiffer. This integral type of body made up from very thin, soft, steel sheet pressed into various shapes and welded together forms a very rigid and light weight unit.

Jacking point. For raising the wheels of the vehicle clear of the ground, a jack is usually used. While jacking up a vehicle, it should be ensured that jack is applied to a part which is sufficiently strong to take load. Special jacking points are now provided on the modern cars for applying jacks to them.

Brakes. For controlling the movement of the vehicles or to stop them, efficient braking system is a necessity for a vehicle. Brakes attached to each of the four wheels are of two types. In the initial type, a pair of shoes carried on a stationary plate is expanded in contact with a rotating drum mounted on the wheels to arrest the motion of the drum. In the modern type of brakes, one or more pairs of pads are carried in a caliper attached to the axle or wheel supporting linkage. The sides of the disc mounted on the wheel are griped by these pads. By applying pressure on a pedal, the brakes are applied. A hand lever acting through a separate linkage and locked in the on-position is used.

For operating the brake, either mechanical or hydraulic system is used. Mechanical system requiring gearing system for mechanical and hydraulic fluid for the hydraulic brakes are used.

Electrical Equipment. Provision for electrical equipment are also made in the layout. For starting the engine, an electric motor produces fuel ignition inside the engine by electric sparks produced by ignition system. Trafficators or indicator lights at front and rear during darkness and fog as well as side lights for turning are required. For operating components like wind screen wipers, horns, direction indicators, heaters, radio receivers etc. electricity is required. The electricity required for operating these equipments is provided by a generator driven by the vehicle engine or by a battery kept charged by the generator.

In addition to one of the most commonly used layout of the automobile components described above, there are other layouts also. They offer better advantages with few drawbacks. The main drawback found in the most usual arrangement is the intruding of the mechanism upon the passenger space. Cars are generally low built with the floor built about 450 mm above the ground level to provide stability and decreased wind resistance to them. To keep the propeller shaft at about floor height, bulge or tunnel is made in the car floor to clear it resulting in reduced space for passenger's feet. The front end of the car body space is further intruded to quite an extent by the gear box. This results in making the nearside door non-usable or difficult to get out by the driver through it. By placing all the mechanism at the end of the car, the long propeller shaft could be eliminated altogether to provide a flat floor and saving in both weight and space.

1·7. Main Components and Assemblies (Constructional Features)

An automobile is a combination of a large number of parts. It can be divided into chassis and body as the two major constituents. Body is the part where the passengers have their seats or the luggage and cargo to be carried is placed. The driver operates the necessary levers, pedals and steering wheel to control the actions of the vehicle from the body itself. To keep the comfort of the passengers and promote the pride of ownership of the vehicle, it is necessary to preserve body finished interior. Chassis is the main machine portion which contain most of the components required for the operation and running of the automobile. The portion of the automobile without body is called chassis. The body fixed over the frame of the vehicle is generally detachable. All parts and accessories needed for the comfort of the human beings are contained in the body of the vehicle. These include doors, windows, lights, fans, seats, air-conditioner and other accessories. The body differing in shape and size from vehicle to vehicle is generally made of steel and wood or steel alone. Driver's seat in case of cars and buses is in one compartment where passengers are sitting. In case of trucks and other loads carriers, the driver's compartment is separate from the main body compartment carrying load and cargo.

The chassis which is the main machine portion have constituents like frame ; wheels ; axles ; springs ; shock absorbers ; engine ; clutch ; gear box ; propeller shaft and universal joints ; differential and half shafts ; steering, brakes and accelerator ; fuel tank ; storage battery, radiator and silencer.

An automobiles in general is made up of the following components : (See Chart 1·1 on next page)

(*i*) The basic structure or the framework.

(*ii*) The engine or power plant or source of power.

(*iii*) The power train or the transmission system.

(*iv*) The body or the super-structure.

(*v*) The auxiliaries.

(*vi*) The controls.

I. The basic structure or the framework. It is backbone of the vehicle. Made of steel with bolted rivetted or welded cross pieces to give it extra strength it has all heavy parts fitted to it. It is that important component of the automobile, which is to support the engine, car body, the wheels and other components. In other words, the basic structure is that unit in which all the other components are to be supported or built. It consists of the frame (integral or non-integral), the suspension system, the axle or the weight carrying portion of the axles, the wheels and tyres.

(*i*) **Frame.** It is the foundation for carrying the engine and body of the vehicle as well as steering, power train etc. by means of springs, axles, rubber pads etc. The frames are made of box, tubular channels or U-shaped section, welded or rivetted together. In order to make them rigid to withstand the shocks, blows, twists and the

Chart 1·1

Main Components of an Automobile

- Chassis
  - Engine of power Plant
    1. Mechanical Components
    2. Cooling System
    3. Fuel System
    4. Ignition System
    5. Lubricating System
    6. Exhaust System
  - Running Gear or the basic structure
    1. Frame
    2. Suspension System
    3. Axles
    4. Spring
    6. Shock absorber
    7. Wheels
    8. Rim and Tyres
  - Driving System
    1. Clutch
    2. Transmission
    3. Drive line or Propeller shaft
    4. Differential
    5. Universal joints
    6. Rear axle
  - Control System
    1. Steering System
    2. Brake System
    3. Control pedals
    4. Control devices
  - Electrical System
    1. Starting System
    2 Charging System
    3. Regulating System
    4. Lighting System
    5. Warning System
  - Accessories (Make driving more pleasant)
    1. Car heater
    2. Air-conditioner
    3. Lights
    4. Radio
    5. Wind screen wiper
    6. Indicates
    7. Horns
    8. Gauges
- Body (skeleton of the vehicle)
  - Convertible
  - Four door Sedan
  - Four door hard top
  - Two door hard top
  - Station Wagon

vibrations met during the operation, cross-bracing or cross members are used. The engine is usually supported at three or four places by providing rubber pads or washers between the support legs on the engine and the brackets on the frame. When the engine, wheels, power trains, brackets and steering systems are fitted on the frames, the assembly is known as the chassis. There are two types of frame constructions commonly in use. It curves upwards at the rear to provide space for the rear springs and to provide space for turning of the front wheels when steered, it is tapered at the front. Standard mark III car has welded box section having longitudinal members sweeping upwards for permiting vertical movement of the rear. To permit sufficient movement to the steering wheels it is tapered from the rear to the front.

(*a*) *Conventional pressed steel or similar frame.* Here all the mechanical components are attached to it and the body is superimposed on it. This is a standard practice for all the commercial vehicles and preferably in the large expensive private and open cars.

(*b*) *The integral or frameless construction.* Here the body structure is designed in such a way as to combine the function of the body and the frame. The components are generally attached to the frame than to the body directly. This is preferably used in case of a closed car where the roof, screen pillars, door pillars and rear panels are the main parts. Single decker bus and double-decker bus are other interesting examples of frameless structure.

(*ii*) **The suspension system.** The various parts are attached to the basic structure by means of springing suspension system. This system is used to prevent the road shocks to the various vehicle components and the occupants and to preserve stability under various road conditions. There are two distinct types of suspension system (*a*) the conventional system, where the road springs are attached to a rigid beam axle. It is mostly used in the front axle of the commercial vehicles and for rear axle of all types of vehicles. (*b*) the independent system ; in this system there is no rigid axle. Each wheel is free to move vertically without any reaction on its mating wheel. This is mostly used in small car rear axle suspensions.

(*iii*) **Axles.** These are the type of beams supported at the ends whether it be front or rear. The weight carrying portions of the axles are loaded at two intermediate points (the spring centres). They are generally subjected to a vertical load at the spring centres due to the weight of the vehicle, a side thrust at the radius of the tyres due to centrifugal force when moving along a curve, a fore and aft load at the wheel centre due to driving or braking effort and the torque reactions due to drive or brake.

The front axle is a simple section forging carrying the king pin at its outer enos. The rear axles are of three distinct types—the fully floating, the three-quarter floating and the semi-floating.

(*iv*) **Wheels.** On account of the light weight and capacity to withstand lateral forces, wire-spoked wheels are generally used on sports and racing cars. In case of private and commercial cars, the pressed steel wheel has replaced these for most of the ordinary purposes. It consists of a central flanged disc pressed into a rolled section rim. It is retained in position by either spot or continuous welding.

II. **The engine or power plant.** The moving power for moving the car, wheels and other parts of automobile is provided by the engine or the power plant. It generally consists of an internal combustion engine. It may be either the spark-ignition or compression-ignition engine. The engines can also be classified as petrol engine and oil engine (both non-volatile and vaporising oil or V.O. engines) according to the fuel used. Rotary engines of Wankel or gas turbine type are being used now-a-days. To minimise air pollution a tendency towards employing external combustion engine like stirling steam engine and fuel cells is controling up. Battery propelled vehicles are also being manufactured and used in big cities.

The gas turbines have also been used recently in certain costly automobiles successfully. Inspite of their better performance as compared to I C. engines, they are not used commonly due to higher cost. To start the engine, an electric starter is provided. It is bolted through rubber blocks on to the chassis. To produce electricity for lights, starter and spark plugs, a generator is provided. To prevent the vibrations of the engine from being transmitted to the vehicle, it is generally bolted to the chassis through rubber blocks.

For better performance, safe working and long engine life, the engine requires four systems namely fuel system, cooling system, lubricating system and ignition system.

III. **The Power train or the transmission system.** This system or mechanism carries the power from the engine to the wheels of the vehicle. It is bolted through the clutch to the engine at the front and the rear to the springs which are connected to the chassis to prevent the engine vibrations from transmitted to vehicle. It generally consists of a friction clutch, a gear-box providing three, or four different ratios of torque (output to input) a propeller shaft for transmitting the torque output from gear-box to the rear axle, a final gear reduction in the rear axle and a differential gear for istributing the final torque between the wheels equally. In certain cases clutch is replaced by fluid flywheels. The function of clutch and gear-box is completely served by the hydraulic torque convertor. The various components of the power train are :

Clutch. It is a friction type uncoupling device. It consists of a single steel disc faced with suitable friction material. It is clamped between two surfaces directly driven by the engine. For disengaging the clutch, the two surfaces are positively separated by pressing the clutch pedal. The main functions of the clutch is to take up the drive smoothly from the engine and to release or disengage that drive whenever desired. The disengagement of clutch is required while changing the gear or bringing the vehicle to rest.

Gear-box. It consists of various types of gears which are constantly in mesh. The gear changes are made by sliding the dogs. The main function of the gear-box is to provide the necessary variation to the torque applied by the engine to the road wheel according to operating conditions. The necessary variations are provided due to the presence of different gears ratios among various meshing gears.

Propeller shaft. It is a universally jointed shaft. Its function is to transmit the power from the reaı end of the gear-box to the final reduction gear in the axle. The vertical movements of the rear axle relative to the frame are also accommodated.

In construction, it is an ordinary Hooke's joint. It contains two devices ; a universal joint and a slip joint. In the joint needle rollers are fitted between the trunnion and the jaws. The shaft is lengthened or shortened or even bent by these two joints to provide flexibility in the joint. The small and limited angular displacement in the rubber joint is advantageous in damping out torsional vibrations.

Universal joint. Due to the flexing of the road springs, the real axle is constantly moving up and down. The propeller shaft fitted to the real axle must also be free to move up or down. To permit the turning of the propeller shaft when this movement is taking place, universal joints are fitted at each of its ends. Thus, the relative movement between the engine and the driving wheel is maintained by the universal joint.

The differential gear. The differential gear carry the power from the propeller shaft to the rear wheel axles. It helps the two rear wheels to turn at different speeds when rounding a curve. The outer wheel must over-run the inner wheels when taking a turn. The differential gear also ensures that the final output torque is equally distributed between the two wheels without any consideration of their relative speeds. The body made of steel and having doors, windows, instruments and lights fitted to it is either bolt d, rivetted or welded to the chassis. In U-bolts with rubber packing (Balates packing) placed between the chassis and body cross members are used for fixing body.

IV. **The body or the super-structure**. In this part of the vehicle passengers ride and are protected from atmospheric effects. In case of conventional pressed steel frame, the body or the body and cab are superimposed. For integral or frameless construc-tion of the basic structure, there is no necessity of separate super-structure or the body. It should be designed in such a way so as to contain and protect the engine and other components as well as the passengers sitting in the vehicle from sun and rain by covering the sides with glass pane. The contours of the body should have a pleasing appearance and provision of sufficient space for the driver and the passengers. The modern tendency is to streamline the vehicle so that its body offers less resistance to its passage through the air. This results in greater power economy at higer speeds due to reduced air resistance. Bolted, rivetted or welded to the chassis, the body generally made of steel sheet has the doors, windows, instruments, doors fitted to it. The truck bodies known as load bodies have only driver compartment as covered while rest of it is uncovered. Some of the bodies are Car, Jeep (open or closed). Truck (full or half body, platform body), Tractor with articulated trailor, dump truck, Tankers, walk in delivery truck, Tractor station wagon, Metador (close or open body), pick-up.

V. **Auxiliaries.** The various auxiliaries of an automobile are fuel system, ignition system, lubrication system, cooling system, the electrical system and their equipments. These would be explained in details in further chapters.

VI. **Controls in an automobile.** In order to keep a motor vehicle under perfect control and reins of the driver, different types of controls are provided in an automobile around the driver's seat, on the dash board and at the foot board. Controls like clutch, brake pedal, accelerator pedal and dimmer switch operated by means of feet are provided at the footboard. Controls actuated by nands are fitted on the dash board and around or on the steering. In front of the driver's seat is located the steering wheel on the steering shaft. On the left or right side of the steering are provided the gear change lever, hand brake and self-starter operating levers. Instrument panel or dash board contains the various switches, instruments, gauges and indicators.

All types of vehicles—cars, buses, lorries or trucks contain the following controls :

Steering, accelerator, clutoh pedal, gear change lever, foot brake pedal, hand brake lever, self-starter lever, dimmer or dipper switch, wiper motor controls, trafficator switch, horn push button ring, engine stop control.

For operating the automobile, a number of switches, control knobs and indicators are required. These provided on the control board or dash board are ignition switch, self-starter switch, lighting switch, throttle control, choke control, speedo-meter, ammeter, oil gauge, fuel gauge, temperature gauge, warning light and electric bell switch. These would be explained in further chapters.

1·8. Specifying an Automobile or Vehicle

For describing an automobile, the various factors are taken into consideration. The various factors are :

1. *Type.* Whether Scooter, Motor cycle, Car, Lorry, Truck etc.

2. *Carriage capacity.* Whether $\frac{1}{4}$ tonne, 15 cwt, 1 tonne, 3 tonnes, 2 seater, 4 seater, 6 seater, 30 seater or 40 seater.

3. *Make.* The name allotted by the manufacturer. It is generally named after the name of the power unit indicating H.P. or number of cylinders or shape of the engine block.

4. *Model.* The year of manufacture or a specific code number allotted by the manufacturer.

5. *Drive.* (*i*) Whether left hand or right hand, *i.e.* the steering is fitted on the left side or right hand side.

(*ii*) Two wheel drive, four wheel drive, six wheel drive. This indicates as to how many wheels, the engine power flows or how many wheels are directly connected with the engine.

Most of the cars are two wheels drive, *i.e.* the power flows to the two rear wheels only and the front wheels are fitted on dead axles.

The jeeps are mostly four wheels drive and all the four wheels are directly connected with the engine. The engine power is supplied to all the four wheels.

For describing a scooter, the specifications are :

(*a*) Type : V—I 1 M Vespa
(*b*) Capacity : 2 persons and 10 kg of luggage
(*c*) Drive : Central drive
(*d*) Make : Vespa—150 c.c.
(*e*) Model : 1970.

Similarly for specifying a truck, the following specifications are given below :

(*a*) Type : Truck 312 *L*
(*b*) Capacity : 17,025 kg
(*c*) Drive : Right hand 6×4 wheels
(*d*) Make : Tata Mercedes-Benz
(*e*) Model : OM 312.

1·9. Resistance to the Motion of the Vehicle

The horse power available at the engine flywheel is about 85% due to loss of power in piston bearings and gears of the engine due to friction. There is a further loss of 10 to 15% due to transmission lines, *i.e.* clutch to drive wheels, due to friction in clutch, gearbox, universal joints, final drive, differential and between tyres and ground. This affects the power available at the road wheels for driving the vehicle.

A thrust known as tractive effort or force is provided by the power unit of a vehicle at the driving road wheels. Varying at different engine speeds and gear positions, it is mainly required to overcome the forces opposing motion of the vehicle. The resistance to the motion of the vehicle is known as tractive resistance. It is the sum of three resistances which are acting on the vehicle. These resistances obstruct the proper movement of the vehicle. These resistances are :

(*a*) Rolling and frictional resistance

(*b*) Gradient resistance

(*c*) Air or wind resistance.

(*a*) **Rolling resistance.** It is the force necessary to maintain constant speed on a level road. The rolling resistance generally varies with the type of the road surface, load on each tyre, inflation pressure and type or tyre tread.

For various types of road surfaces, this resistance is as shown in the table below :

Road Surface	*Resistance kg/tonne*	*Road surface*	*Resistance kg/tonne*
Rail-road	4·5	Soft macadam	43·6
Good Asphalt	6·75	Well-rolled Gravel	25·7
Medium Asphalt	9·9	Small cobbles	27·0
Poor Asphalt	13·1	Medium cobbles	58·5
Wood Paving	13·5	Large cobbles	108·0
Granite setts	15·75	Hard dry clay	45·0
Best Macadam	20·2	Sand road	162·0
Ordinary Macadam	22·5—27	Loose sand	252·0

Except for military and agricultural vehicles (tractors etc.), an average value for rolling resistance in case of most of the vehicles is 22·5. It is about 33% less for cord tyres than that of the fabric tyres in the speed range of 32 to 80 km/hr. For smooth concrete pavement the average value of rolling resistance is $16{\cdot}9+0{\cdot}032\,V$ per 1000 kg. where V is the speed in kph.

Frictional resistance to motion of the vehicle is due to transmission losses. These losses are due to the effect of gear efficiencies, oil churning, tyre adhesion etc. An empirical formula for calculating this resistance is given as

$$f=66{\cdot}6+0{\cdot}012\,W$$

where f=frictional resistances in kg.

W=total weight of the vehicle in kg.

These transmission losses are enerally 10 per cent in direct gear and 15—20 per cent in low gear. For calculating performance tractive force should be estimated at efficiencies of 90 per cent top gear and 80—85 per cent for low gear. This figure also includes temperature losses and the losses occurring in oil churning in a closely designed gearbox and confined rear axle. For private cars, these figures are 89—95 per cent. The friction loss in the tyres is about two-thirds that of total loss in the chassis.

Another formula for rolling resistance

$$R_r = K_r W$$

where K_r=constant rolling resistance
and W=total weight of the vehicle in kg.

The nature of the road surface and type of the tyres, *i.e.* whether pneumatic or solid rubber tyres determine the value of the constant K. The value of K are respectively 0·0095 and 0·18 for best roads and loose sandy roads.

(*b*) **Gradient resistance.** It is the force opposing forward motion of a vehicle up a gradient.

This resistance does not depend on the speed of the vehicle.

It is a function of the vehicle weight and the gradient. It is generally expressed as $P = W/G$

where G=Gradient
W=Weight of the vehicle in kg
P=Gradient resistance and
$\cong W \sin \theta$

where θ=inclination.

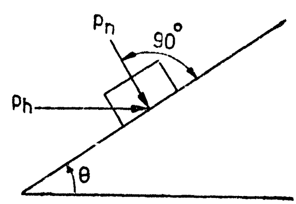

Fig. 1·4.

When expressed as a percentage, it is per cent gradient

$$= 100 \times \tan \theta \cong 100 \sin \theta$$

(*c*) **Wind or air resistance.** This resistance depends upon the speed of the vehicle, wind velocity, size and shape of the body of the vehicle. It is calculated from the fromula :

$$p_n = p_h \frac{2 \sin \theta}{1 + \sin^2 \theta}$$ (From head on direction of the wind)

and $$p_h = kV^2 A$$ (For the same flowing direction of the wind)

where k is a co-efficient depending upon the amount of streamlining effect on the car's exterior or the angle of inclination of the surface to the normal ; A, the forwardly projected area in square metres, and V, the speed of the vehicle in km/hr. An average value of this co-efficient for modern streamlined car is 0·003213. But for a perfectly streamlined body, its value is 0·031134. For single deck streamlined body is 0·003975 and for a double-deck passenger vehicle it is 0·0061.

The trucks, buses and other commercial vehicles are not streamlined, therefore, their air resistance co-efficients are higher. The value of this co-efficient for these types of vehicles is 0·004575 to 0·004715 with a safe value of 0·004725. Its units are kg-hr²/m² km².

The Tractive Resistance is expressed as

Gradient resistance+Rolling resistance+Air resistance

or

$$TR = W\left(R_r + \frac{1000}{G} \right) + kV^2A$$

where
TR=Tractive resistance in kg.
W=Weight of the vehicle in tonnes
R_r=Rolling resistance in kg/tonne
G=Gradient
V=Velocity in km.p.h.
A=Projected area in sq. metres.

For smooth concrete pavement having a gradient, the tractive resistance is given ;

$$TR = (16{\cdot}9 + 0{\cdot}032V)\ W + W \times 1000 + 0{\cdot}003213\ AV^2$$

Forces opposing forward motion of a vehicle moving up a Slope=Gradient resistance+Rolling resistance +Air Resistance

$$= W \sin\ \alpha + WR_r + R_a = \frac{W}{G} + WR_r + R_a$$

Forces producing forward motion of a vehicle moving down a slop—Gradient resistance—Rolling resistance+Air resistance.

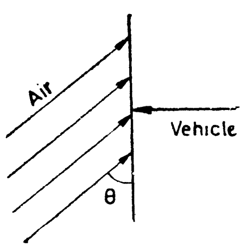

Fig. 1·5

$$= W \sin\ \alpha - WR_r + R_a = \frac{W}{G} + R_a - WR_r$$

$$= \frac{R_g}{G} + R_a - R_r.$$

For calculating air resistance, the vehicle road speed and both the speed and direction of the wind must be known. When the wind is opposing the motion, these must be added to the vehicle and subtracted if moving in the same direction. When the direction of the wind is different from the direction of the vehicle movement, the air resistance will vary as sin θ.

Traction and tractive effort. Tractive effort is the force available at the points of contact between the rear wheel tyres and the road. The traction on the other hand, is the ability of the rear wheels to transmit the tractive effort without slipping. Therefore, the useful tractive effort is always less than traction.

If
T_e = Mean engine torque in kg-m
T_w = Torque at the rear wheels in kg-m
P_e = Engine b.h.p.
η_t = Overall transmission efficiency
g_r = Gear box gear ratio
a_r = Back axle ratio
G_r = Overall gear ratio $= g_r \times a_r$
N = r.p.m. of the crank shaft
F_t = Tractive effort
R_t = Total resistance on level road.

$$\therefore \text{ Engine torque, } T_e = \frac{4500 \times P_e}{2\pi N} = \frac{716\, P_e}{N}$$

and torque at rear wheels

$$T_w = (g_r \times a_r) \times \eta_t \times T_e$$
$$= G_r \times \eta_t \times T_e$$
$$= G_r \times \eta_t \times \frac{716\, P_c}{N}$$

Now tractive effort,

$$F_t = \frac{\text{Torque at the rear wheels}}{\text{Radius of the wheels}}$$

$$\therefore \quad F_t = \frac{T_w}{r} = \frac{T_e \times G_r \times \eta_t}{r}$$
$$= \frac{716\, P_e \times G_r \times \eta_t}{N\,.\,r}$$

If the total resistance on level road is R_t, less than the tractive effort F_t, the surplus tractive effort available is used for acceleration, hill climbing and drawbar pull.

The relation between the revolutions of the engine (N) and the speed of the vehicle is given by

$$\frac{2\pi\, r\, N}{G_r} = \frac{V \times 1000}{60}$$

or

$$\frac{N}{V} = \frac{1000\, G_r}{2\pi \times 60}$$
$$= 2{\cdot}65 \left(\frac{G_r}{r}\right)$$

where V is in km/hr and r is the radius of wheel in metres

This shows that $\frac{N}{V}$ ratio depends upon overall gear ratio G_r. A vehicle having different gear ratios will have different values of $\frac{N}{V}$.

Acceleration. Depending upon the moment of inertia and gear ratio, the rotating parts of the vehicle are also accelerated due to acceleration of the vehicle. This results in increase of weight of the vehicle to use. It is known as effective weight of the vehicle. By utilizing the excess power or surplus tractive effort to provide acceleration to the vehicle, we get

Surplus or excess power

$$=\frac{W_e}{g} \cdot \frac{a \times V}{270}$$

or Acceleration $a=\frac{g}{W_e}$ (surplus power or h.p) $\times \frac{270}{V}$

$$=\frac{g}{W_e}(P_e-P_r)\ \eta_t \times \frac{270}{V}$$

$$=\frac{g}{W_e}\ (P_e.\eta_t-P_r\eta_t)\times \frac{270}{V}$$

$$=\frac{g}{W_e}\ (\text{Tractive effort}-\text{Road resistance})$$

$$=\frac{g}{W_e}\ (F_t-R_t).$$

Gradiability. It is the maximum percentage grade negotiated by a vehicle under full rated condition.

$\therefore$ Surplus h.p $=\frac{\text{Weight of vehicle}\times\text{Gradiability}\times\text{Speed}}{100\times 270}$

$\therefore$ Gradiability $=\frac{100}{W}$ (Surplus h.p.) $\times \frac{270}{V}$

$$=\frac{100}{W}\ (P_e\eta_t-P_v)\times \frac{270}{V}$$

$$=\frac{100}{W}\ (\text{Tractive effort}-\text{Road resistance})$$

$$=\frac{100}{W}\ (F_t-R_t).$$

Drawbar pull. If the extra load attached to the vehicle is pulled by fully utilizing the excess power, therefore,

Maximum drawbar pull

$$=\text{Tractive effort}-\text{Road resistance}$$

$$=F_t-R_t$$

where $R_t=R_a+R_r$

$$=\text{Air resistance}+\text{Rolling resistance}.$$

1·10. Power Requried for Propulsion of the Vehicle

It consists of the power absorbed in overcoming the resistance and the friction in transmission.

Let the car is travelling at V km p.h It covers a distance of 16·66 metres/minute.

Therefore, the work done per minute when the car is moving at this speed on a smooth concrete pavement having a gradient is given as (Tractive resistance)×(Distance covered per minute).

$$\therefore \quad \text{Work done} = \left[(16{\cdot}9 + 0{\cdot}032\,V)\,W + \frac{W \times 100}{G} + 0{\cdot}003213\,AV^2 \right] \times 16{\cdot}66\,V \text{ metre kg.}$$

Now 1 H.P. is equal to 4500 m-kg per metre, the horse power absorbed in overcoming the resistance is

$$\therefore \quad \text{H.P.}$$

$$= \frac{\left[(16{\cdot}9 + 0{\cdot}032\,V)\,W + \dfrac{W \times 1000}{G} + 0{\cdot}003213\,AV^3 \right] \times 16{\cdot}66\,V}{4500}$$

$$= \frac{\left(16{\cdot}9\,V + 0{\cdot}032\,V^2 + \dfrac{1000\,V}{G} \right) W + 0{\cdot}003213\,AV^2}{269{\cdot}95}$$

For a vehicle moving on a level road, only the rolling and air resistances are encountered and no gradient resistance is encountered.

$$\therefore \quad \text{H.P.} = \frac{(16{\cdot}9\,V + 0{\cdot}032\,V^2)\,W + 0{\cdot}003212\,AV^3}{269{\cdot}95}$$

For calculating the power required to overcome the friction in the drive, the efficiency to transmission for different drives should be taken into consideration. For direct drives with reduction ratio upto 7, the efficiency is 90% while for geared drives with an overall reduction ratio of 12, it reduces to 84% and to 80% for an overall reduction artio of 20.

Now the engines of same size are generally used in vehicles of widely different gross weights.

The axle friction accounts for more than one-half the total friction loss. This friction is more dependent on the gross vehicle weight than on the engine efficiency or output. The frictional loss in the drive is due to the transmission and the driving axle. The size of transmission for a fixed number of gear ratio is calculated by the size of the engine. The size of the driving axle is dependent upon the gross weight of the vehicle.

The frictional losses should, therefore be calculated taking into consideration both the gross vehicle weight and the engine output or drive efficiency.

The friction torque of the drive referred to the crankshaft axis is given by the equation,

$$T_f = C\sqrt{wD} \text{ kg-metre.}$$

where w is the gross weight of the vehicle expressed in units of 1000 kg ; D, is the piston displacement in cu cm and C is a constant. For trucks with four-speed transmissions C is equal to about 2·415 for direct drive, about 3·025 for third speed and about 3·22 for second speed.

Power required to propel a vehicle is also given

$$P_v = \frac{R_t \times V \times 1000}{4500 \times 60} = \frac{R_t \times V}{270} \text{ h.p.}$$

where $R_t = (R_a + R_r)$

when vehicle moves along a level road.

Required power to take transmission losses

$$P_r = \frac{P_v}{\eta_t} = \frac{R_t \times V}{270\eta_t} \text{ h.p.}$$

$$= R_t = (R_a + R_r + R_g)$$

when it moves up a gradient.

1·11. Power Required for Acceleration

In order to get a vehicle up to a certain speed, the power required is usually more than that required to maintain it at a uniform speed under similar conditions. The amount of kinetic energy stored up by a car in motion is used by it during the acceleration period.

Force required to produced (linear) acceleration is given by the expression

$$F = \frac{W}{g} \cdot a \text{ kg.}$$

where W=weight of the mass of body being accelerated in kg.
a=acceleration in metres per sec²
g=acceleration due to gravity in metres/sec
=9·11 min/sec².

The linear acceleration in case of a motor vehicle is generally accompanied by angular acceleration of the road wheels, axle shafts, differential gear, propeller shaft, transmission gear, clutch, flywheel and other rotating parts of the engine. The increase and decrease in the rotary speeds of these parts takes place with variation in the car speed. In order to overcome the inertia of these rotating parts additional engine torque is required. For producing a linear acceleration force is directly proportional to the accelerated weight. For angularly accelerating a body, a torque or moment should be applied. The moment required for producing a certain angular acceleration various directly with moment of inertia of the body. The angular velocity ω is expressed in radian per second.

For producing an angular acceleration α, the moment or torque is given by the expression

$$\tau = \frac{J}{g} \alpha$$

where τ=moment of inertia of the body around its axis in kg-m²
g=acceleration due to gravity
a=angular acceleration in radians/sec².

Out of the various rotating masses of a motor vehicle mentioned above, the masses ahead of the rear axle rotate at a higher angular velocity than the axle. For finding the effect of rotating part on the force or torque needed to produce vehicle acceleration, the moments of inertia of parts ahead of the axle should be reduced to equivalent moments of inertia of the parts rotating with axle shaft or the road wheels. For this purpose the moments of inertia of the faster-rotating parts should be multiplied by the square of the axle ratio. If r is the ratio ; J_e kg-metre, the moment of inertia of all the rotating parts with the engine crankshaft and J_a, the moment of inertia of the parts rotating with the axle or road wheels, the equivalent moment of inertia of all the rotating parts with the road wheels is now reduced to $(r^2J_e+J_a)$ kg-m². Thus in other words, the moment of inertia of a mass of $(r^2J_e+J_a)$ kg at a distance of 1 metre kg from the axis of the wheel or a mass of $(r^2J+J_a)/R^2$ kg located on the circumference of the road wheel R is the effective radius of the wheel in metres. Now the peripheral velocity of the wheel is the same as the linear velocity of the vehicle. Therefore, the effect of the rotating parts on the vehicle acceleration is equivalent to the effect of a weight addition of $(r^2J_e+J_a)/R^2$ kg to the weight of the vehicle.

The equivalent additional car weights of the rotating parts for acceleration in first gear, second gear and in direct drive can be determined easily.

Let W=weight of the car in kg.

I_r=moment of inertia of faster rotating parts with the crankshaft in kg-m². (Parts are crankshaft, connecting rod big ends, flywheel, clutch and parts of transmission revolving at crankshaft speed).

I_a=moment of inertia of slower rotating parts (driving wheels, axle shafts and differential gear) revolving at axle speed in kg-m².

r_a=axle ratio.

r_i=ratio of the intermediate gear in the transmission.

r_l=ratio of the low gear.

R_w=effective radius of driving wheel in metres.

The parts like the main drive shaft of the transmission with the gears thereon, the propeller shaft and universal joints, though in permanent driving connection with the rear axle rotate at an increased speed. They have a compaiat vely low moments of inertia. Therefore, it is generally neglected.

Therefore, the moment of inertia of parts rotating with the crankshaft when reduced to axle speed for acceleration in high or first gear

$$= I_r \times r_a \times r_a \text{ kg-m}^2 = I_r \,.\, r_a^2$$

Total moment of inertia of the parts rotating with crankshaft and revolving at axle speed

$$= I_r \,.\, r_a^2 + I_a.$$

In order to convert this into equivalent car weight, divide it by the square of the effective wheel radius in metres

$$\frac{I_r \,.\, r_a^2 + I_a}{R_w^2}$$

In percentage, it is $= \dfrac{I_r r_a^2 + I_a}{R_w^2} \times \dfrac{100}{W}.$

For parts rotating with the crankshaft reduced to axle speed the moment of inertia in intermediate gear or second gear is

$$I_r \times r_a \times r_a \times r_t \times r_t = I_r \,.\, r_a^2 \,.\, r_t^2 \text{ kg-m}^2$$

Total moment of inertia of parts rotating with the crankshaft and the axle

$$= I_r \,.\, r_a^2 \,.\, r_t^2 + I_a.$$

$\therefore$ Equivalent weight of the car

$$= \frac{I_r . r_a^2 . r_t^2 + I_a}{R_w^2}$$

In percentage $= \dfrac{I_r . r_a^2 . r_t^2 + I_a}{R_w^2} \times \dfrac{100}{W}.$

Similarly the equivalent weight of the car in the low or third gear will be

$$\frac{I_r \, r_a^2 . r_t^2 + I_a}{R_w^2} \times \frac{100}{W}.$$

The equivalent weight can also be calculated by taking into consideration, the engine torque T_e, transmission efficiency η_t, overall gear ratio G_r, angular acceleration of faster rotating part α_a and angular acceleration of slower rotating parts α_i.

Taking into consideration, the inertia of faster rotating parts or the engine masses, the effective to que on the driving crankshaft

$$= \left(T_e - \frac{I_a}{g} \alpha_a \right) \eta_t \times G_r \text{ kg-m}.$$

Taking into consideration, the inertia of slower rotating parts, *i.e.* driving wheels, axle shafts and differenntial gear etc.

Torque at the driving wheels

$$=\left[\left(T_e-\frac{I_a a}{g}\right)\eta_t G_r-\frac{I_i a_i}{g}\right] \text{kg-m.}$$

∴ Tractive effort available at the wheels

$$=\frac{1}{R_w}\left[\left(T_e-\frac{I_a a_a}{g}\right)\eta_t G_r-\frac{I_t a_i}{g}\right] \text{kg.}$$

This tractive force available at the wheels must be equal to the tractive force required to overcome road resistance and that required acceleration.

$$\therefore \quad \frac{1}{R_w}\left[\left(T_e-\frac{I_a\alpha_a}{g}\right)\eta_t G_r-\frac{I_t a_t}{g}\right]=R_t+\frac{W}{g}a$$

or

$$\frac{\eta G_r T_e}{R_w}-R_t=\frac{W}{g}a+\frac{I_a\alpha_a}{y\times R_w}+\frac{I_t a_t}{R_w}$$

Now $\quad a_a=\alpha_i\times G_r=\frac{a}{R_w}\times G_r.$

Substituting the values of a_a and a_i, we get

$$\frac{\eta_t G_r T_e}{R_w}-R_t=\frac{W}{g}a+\frac{I_a\eta_t G_r^2 a}{gR_w}+\frac{I_t a}{gR_w^2}$$

$$=\left(W+\frac{I_a\eta_t G_r^2+I_t}{R_w^2}\right)\frac{a}{g}.$$

We know that acceleration,

$$a=\frac{g\text{ (Tractive effort—Total road resistance)}}{\text{Equivalent weight}}$$

∴ Equivalent weight,

$$W_e=W+\frac{I_a\eta_t G_g^2+I_i}{R_w^2}$$

The gear ratio for maximum acceleration can be found by equating the differential of acceleration *a* with respect to G_r to zero.

Now, from the above expression

$$\left(\frac{\eta_t G_r T_e}{R_w}-R_t\right)=\left(W+\frac{I_a\eta_t G_r^2+I_i}{R_w^2}\right)\frac{a}{g}$$

$$a=\frac{T_e G_r\eta_t-R_t R_w}{\left(\frac{W}{g}R_w+\frac{I_i}{gR_w}\right)+\frac{I_a\eta_t G_r^2}{gR_w}}\ \text{metre/sec}^2$$

Let $\quad T_e\eta_t = A,\ R_t R_w = B,$

$$\frac{W}{g} R_w + \frac{I_t}{gR_w} = C \quad \text{and} \quad \frac{I_v \eta_t}{gR_w} = D.$$

$$\therefore \quad a = \frac{AG_r - B}{C + DG_r^2}.$$

Now, for acceleration a to be maximum

$$\frac{da}{dG_r} = 0$$

or
$$\frac{(C + DG_r^2)A - (AG_r - B)2DG_r}{(C + DG_r)^2} = 0$$

or
$$A(C + DG_r^2) - (AG_r - B)2DG_r = 0$$

or
$$G_r^2(AD - 2AD)2BDG_r + AC = 0$$

or
$$G_r^2 - \frac{2BD}{AD} G_r - \frac{C}{D} = 0$$

or
$$G_r = \frac{\frac{B}{A} \pm \sqrt{\left(\frac{2B}{A}\right)^2 + 4\frac{C}{D}}}{2}$$

$$= \frac{B}{A} \pm \sqrt{\left(\frac{B}{A}\right)^2 + \frac{C}{D}}$$

$$\frac{R_t R_w}{T_e\eta_t} \pm \sqrt{\left(\frac{R_t R_w}{T_e\eta_t}\right) + \frac{2\frac{W}{g} R_w + \frac{I_t}{gR_w}}{I_a\eta_t/gR_w}}$$

Substituting this value of

$$G_r = \frac{R_t R_w}{T_e\eta_t} \pm \sqrt{\left(\frac{R_t R_w}{T_e\eta_t}\right)^2 + \frac{\frac{W}{g} R_w + \frac{I_t}{gR_w}}{\frac{I_a\eta_t}{gR_w}}}$$

into the above expression the value of maximum acceleration can be found.

Power-Weight Ratio. It is the basic factor of performance of an automobile. To achieve best performance weight of the vehicle should be kept minimum and engines of high b.h.p. should be installed. Further better hill climbing abilities, the higher maximum speed and better acceleration of the vehicle are obtained by keeping the higher effective b.h.p. of the engine and the lower total weight of the vehicle. At any given speed, a low fuel consumption will be registered by a well designed streamlined vehicle with a power-weight ratio.

Progressive increase in power-weight ratio resulted due to considerable reduced automobile weight by the use of lighter materials and improved methods of chassis and body construction.

The use of aluminium and magnesium alloys, improved piston ring, cylinder and combustion chamber designed, increased compression ratios due to use of aluminium alloy pistons and cylinder heads, better engine balancing, lubrication and cooling systems, fuels of higher octane values, balanced fuel supply and correct ignition result in increased power output of the engine.

Power to weight ratio which in b.h.p. per tonne ranges from 30 to 90 in small and medium cars and upto 230 in case of special high performance vehicles. In addition to high power weight ratio for maximum speed, there should be minimum body resistance because the power varies as the cube of speed while the air resistance of an automobile body and chassis increases as the square of speed. The road performance of a vehicle is assessed by its rate of acceleration from rest and the maximum speed attainable on level roads while the power-weight ratio and the resistances affecting its movement govern the performance of the automobile.

Example 1·1. *Find the additional equivalent weight of car for the rotating parts in the first gear, second gear and in the direct drive when the following specifications of a car are given :*

Weight of the car =*157ɔ kg*

Moment of inertia of parts rotating with the crankshaft

=*0·5225 kg-m²*.

Moment of inertia of parts rotating with axle speed

=*6·725 kg-m²*.

Axle ratio =*4·5*.

Frontal area of the car

=*8·54 sq m*.

Ratio of intermediate gear in transmission

=*1·62*.

Ratio of low gear =*2·75*.

Effective radius of driving wheels

=*0·351 m*.

Also calculate the engine torque required for acceleration when the car is capable of a maximum acceleration of 4 km/hr/sec.

Solution. For acceleration in high or top gear, the moment of inertia of parts rotating with the crankshaft

$$=0{\cdot}5225\times4{\cdot}5\times4{\cdot}5$$
$$=10{\cdot}495 \text{ kg-m}^2.$$

Total moment of inertia of parts rotating with crankshaft and revolving at axle speed

$$=14{\cdot}495+6{\cdot}725$$
$$=17{\cdot}200 \text{ kg-m}^2.$$

The equivalent car weight is obtained by dividing this by the square of the effective radius

$$=\frac{17{\cdot}22}{0{\cdot}1235}=139{\cdot}5 \text{ kg.}$$

In percentage it is equal to

$$\frac{139{\cdot}5\times 100}{1575}=8{\cdot}86\% \text{ of the car weight.}$$

In intermediate gear, the moment of inertia of parts rotating with the crankshaft, reduced to axle speed

$$=0{\cdot}5225\times(4{\cdot}5)^2\times(1{\cdot}62)^2$$

$$=27{\cdot}50 \text{ kg-m}^2.$$

Total moment of inertia of parts rotating with crankshaft and revolving at axle speed

$$=27{\cdot}50+6{\cdot}725=34{\cdot}225 \text{ kg-m}^2.$$

∴ Equivalent car weight

$$=\frac{34{\cdot}225}{0{\cdot}1235}=275 \text{ kg}$$

In percentage $=\frac{275\times 100}{1575}=17{\cdot}6\%$ of the car weight.

For low gear, the moment of inertia of the parts rotating with the crankshaft reduced to axle speed

$$=0{\cdot}5225\times(4{\cdot}5)^2\times(1{\cdot}62)^2\times(2{\cdot}75)^2$$

$$=209{\cdot}45 \text{ kg-m}^2.$$

Total moment of inertia of parts

$$=209{\cdot}45+6{\cdot}725$$

$$=216{\cdot}175 \text{ kg-m}^2.$$

∴ Equivalent car weight

$$=\frac{216{\cdot}175}{0{\cdot}1235}=1750 \text{ kg}$$

∴ In percentage $=\frac{1750\times 100}{1575}=111{\cdot}5\%$

or $111{\cdot}5-100=11{\cdot}5\%$ additional car weight.

For accelerating in direct drive, the equivalent weight of the car is equal to the sum of the weight of the car and the percentage of equivalent weight required for accelerating in the high gear.

∴ Equivalent weight

$$=1{\cdot}09\times 1575=1715 \text{ kg.}$$

Force required to produce an acceleration of 4 km per hour per second.

111 cm per sec^2 $= \frac{1715 \times 111}{981} = 194$ kg

Now axle torque for effective radius of 0·351 metre

$= 194 \times 0{\cdot}357 = 69{\cdot}25$ kg-m.

The engine torque for an axle ratio of

$4{\cdot}5 = \frac{69{\cdot}25}{4{\cdot}5} = 15{\cdot}4$ kg-m.

In order to account for frictional losses in the transmission and drive, ten per cent more should be added.

∴ The engine torque required

$= 16{\cdot}94$ kg-m.

The combined rolling and air resistance when the car is running at 40 kmph with an allowance of 250 kg for supplies and passengers is

$0{\cdot}032 \times 1825 + 0{\cdot}003213 \times 8{\cdot}54 \times 40 \times 47$

$= 58{\cdot}25 + 43{\cdot}75 = 102$ kg.

This is equal to an engine torque of

$\frac{102 \times 0{\cdot}351}{4{\cdot}5} = 7{\cdot}95$ kg-m.

Therefore, the engine should be capable of delivering $(16{\cdot}94 + 7{\cdot}95) = 24{\cdot}89$ kg-metre of torque at 40 kmph. (1370 r.p.m.)

Effect of different drive. The different types of drives used in automobiles, *i.e.* front wheel drive, rear wheel drive and four wheel drive with or without third differential effect the maximum acceleration, maximum tractive effort and reactions.

1. Front wheel drive. Consider a vehicle with different forces acting as shown in Fig. 1·6.

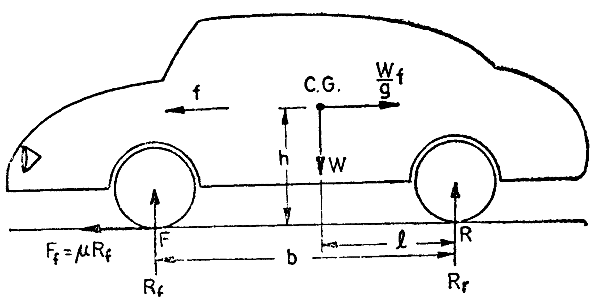

Fig. 1·6

Let b = wheel base

l = distance of line of action weight or C.G. from the rear axle.

μ = coefficient of adhesion between the tyres and the road surface.

h = height of C.G. from the road surface.

R_f and R_r = total normal reactions at the front and rear axles respectively.

W = weight of the vehicle.

a = maximum forward acceleration.

Now maximum tractive force

$$=F_f=\mu R_f.$$

A maximum forward acceleration a and an inertia force $\frac{W}{g}$ a opposite to a is produced due to the effect of F_f.

For dynamic equilibrium,

Algebraic sum of the vertical forces

or $$\Sigma V=0$$

Algebraic sum of the horizontal forces

or $$\Sigma H=0$$

Algebraic sum of the moments about R,

i.e. $$\Sigma M_r=0$$

From $\Sigma V=0$,

we get $$W=R_f+R_r$$

From $\Sigma H=0$, we get

$$F_f=\mu R_f \frac{W}{g}.\ a$$

and from $\Sigma M_r=0$, we get

$$R_f \times b+\frac{W}{g}\, a \times h=W \times l.$$

Substituting the value of R_f, we get

$$\frac{W.a.b}{g.\mu}+\frac{W}{g} a \times h=Wl$$

or $$\frac{a}{g}\left(\frac{b}{\mu}+h\right)=l$$

$$\frac{a}{g}=\frac{\mu l}{b+\mu h}$$

$\therefore$ $$R_f=\frac{W.\mu l}{\mu(b+\mu h)}=\frac{W.l}{b+\mu h}$$

$$R_f = W - R_f = W - \frac{Wl}{b+\mu h}$$

$$= \frac{W(b+\mu h - l}{b+\mu h}$$

(*ii*) **Rear wheel drive.** In this case, the tractive force is acting on the rear wheels only. Therefore, the maximum tractive force on rear wheels $Fr = \mu Rr$.

For dynamic equilibrium ;

$$\Sigma V = 0,\ \Sigma H = 0,\ \Sigma M_f = 0.$$

From the above equations, we get

$$W = R_r + R_f$$

$$F_r = \mu Rr$$

$$= \frac{W}{g}.a$$

$$R_r \times b = W(b-l) + \frac{W}{g} a \times h.$$

Substituting the values of R_r in the above equation, we get

$$\frac{W}{g} \times \frac{a}{\mu} \times b = W(b-l) + \frac{W}{g} a \times h$$

or $$\frac{a}{g}\left(\frac{b}{\mu} - h\right) = b - l.$$

$\therefore$ $$\frac{a}{g} = \frac{\mu(b-l)}{a-\mu h}$$

Hence $$R_r = \frac{W}{g} \cdot \frac{a}{\mu} = \frac{W}{\mu} \cdot \frac{a}{g}$$

$$= \frac{W}{\mu} \cdot \frac{\mu(b-l)}{b-\mu h} = \frac{W(b-l)}{b-\mu h}.$$

Similarly, $$R_f = W - R_r$$

$$= W - \frac{W(b-l)}{b-\mu h}$$

$$\frac{W(b-\mu h - b + l)}{b+\mu h} = \frac{l-\mu h}{b-\mu h} W.$$

(*iii*) **Four wheel drive.** In this drive, two cases will be considered with or without a third differential.

(*a*) *With third differential.* With the application of the third differential, the torque at the front and rear wheels will be equal. The tractive effort is limited due to the occurrence of the slip at the wheel where the normal reaction is smaller. For equal load distribution on the front and the rear wheels, the slip occurs first at the front wheels and then at the rear wheels. This is due to the reduction of the static normal reaction at the wheels by the inertia forces.

Now for dynamic equilibrium ;

$$\Sigma V=0,\ \Sigma H=0 \text{ and } \Sigma Mr=0$$

By the application of the third differential

$$\mu R_f = \mu_s Rr$$

where μ_s is the critical working co-efficient of friction.

Its value is always less than the limiting value of μ

$$\therefore \qquad W = Rr + R_f$$

$$\frac{W}{g}\ a = \mu_s\ Rr + \mu R_f$$

Suppose the slip occurs at the front wheels first, *i.e.* $R_f < Rr$

$$\therefore \qquad \frac{W}{g} \times a = \mu R_f + \mu R_f = 2\mu R_f$$

When $\qquad \Sigma Mr = 0,$

$$R_f \times b + \frac{W}{g} a \times h = W \times l.$$

By substituting the value of R_f, we get

$$W \times \frac{a}{g} \times \frac{b}{2\mu} + W \times \frac{a}{g} \times h = Wl$$

or

$$\frac{a}{g}\left(\frac{b}{2\mu} + h\right) = l$$

or

$$\frac{a}{g} = \frac{2\mu l}{b + 2\mu h}.$$

Substituting the value of $\frac{a}{g}$, to find the value of R_f and Rr, we get

$$R_f = \frac{W}{g}\ a . \frac{1}{2\mu}$$

$$= \frac{2\mu l}{b + 2\mu h} . W . \frac{1}{2\mu}$$

$$= \frac{l}{b + 2\mu h} . W.$$

$$Rr = W - R_f = W - \frac{1}{b + 2\mu h} . W$$

$$= \frac{b + 2\mu h - l}{b + 2\mu h} . W.$$

In case the slip occurs first at the rear wheels, $Rr < R_f$.

$$\therefore \qquad 2\mu Rr = \frac{W}{g} . a.$$

Now for dynamic equilibrium,

$$\Sigma M_f = 0.$$

$$R_r \times b = W(b-l) + W \times \frac{a}{g} \times h.$$

By eliminating R_r from the above two equations, we get

$$W \times \frac{a}{g} \times \frac{b}{2\mu} = W(b-l) + W \times \frac{a}{g} \times h$$

$$\frac{a}{g}\left(\frac{b}{2\mu} - h\right) = b -$$

$$\therefore \quad \frac{a}{g} = \frac{(b-l)\,2\mu}{b-2\mu h}.$$

Substituting this value in the moment equation to find the values of R_r and R_f, we get

$$R_r = \frac{W}{g} \times \frac{a}{2\mu} = \frac{W}{2\mu} \times \frac{a}{g}$$

$$= \frac{W}{2\mu} \cdot \frac{(b-l)2\mu}{b-2\mu h}$$

$$= \frac{b-l}{b-2\mu h}.W.$$

$$R_f = W - R_r$$

$$= W - \frac{b-l}{b-2\mu h} W$$

$$= \frac{b-2\mu h-b+l}{b-2\mu h}.W$$

$$= \frac{l-2\mu h}{b-2\mu h}.W.$$

(*b*) *Without the third differential.* When there is no third differential, both F_f and F_r are acting on the vehicle. Suppose the limiting friction occurs at al four wheels simultaneously, there fore, the maximum tractive effort is given as

$$F_{max} = F_r + F_f = \mu R_r + \mu R_f.$$

For dynamic equilibrium,

$$\Sigma V = 0, \ \Sigma H = 0.$$

$$\therefore \quad W = R_f + R_r$$

and

$$\frac{W}{g} a = \mu R_r + \mu R_f$$

$$= \mu (R_r + R_f) = W.\mu$$

$\therefore \quad \frac{W}{g}.a=\mu W$

or $\quad \frac{a}{g}=\mu.$

The value of maximum acceleration, maximum tractive effort and reactions for different drives in the above cases have been found for the vehicles moving on level road. By taking into consideration the inclination of the grade θ, the values for vehicles moving on grades can be calculated by a similar treatment.

Problem 1·2. *The co-efficient of rolling resistance for a track weighing 6350 kg is 0·018 and co-efficient of air resistance is 0·00281 in the formula* $R=kW+k_aAV^2$ *kg ; where A is* m^2 *of frontal area and V the speed in km/hr. The transmission efficiency in top gear of 6·1 : 1 is 20% and that in the second gear of 15 : 1 is 80%. The frontal area is 5·574* m^2. *If the truck has to have a maximum speed of 88 km/hr in top gear, calculate*

(*i*) *the engine b.h.p. required* ;

(*ii*) *the engine speed of the driving wheels have an effective diameter of 81·25 cm* ;

(*iii*) *the maximum grade the truck can negotiate at the above engine speed in the second gear* ; *and*

(*iv*) *the maximum drawbar pull available on level at the above engine speed in second gear.* (*P.U. 1966 Suppl.*)

Solution. The total resistance

$$R=kW+K_aAV^2$$

For top gear ;

$$K=0{\cdot}018$$
$$K_a=0{\cdot}00281$$
$$W=6350 \text{ kg}$$
$$V=88 \text{ km/hr.}$$
$$A=5{\cdot}574 \text{ m}^2$$

∴ Resistance $R=0{\cdot}018\times6350+0{\cdot}00281\times5{\cdot}574\times(88)^2$
$=114{\cdot}30+121{\cdot}6=235{\cdot}9$ kg.

(*i*) Now engine b.h.p.

$$P_e=\frac{R_r\times V}{75\times\eta_t}=\frac{235{\cdot}9\times88\times1000}{75\times0{\cdot}9\times3600}$$
$$=85{\cdot}35 \text{ h.p.}$$

(*ii*) Now engine speed,

$$V=\frac{2\pi r\ N}{G_r}$$

or

$$N=\frac{V\,G_r}{2\pi r}=\frac{88\times1000\times2\times6{\cdot}2}{2\pi\times81{\cdot}25\times100}$$
$$=3560 \text{ r.p.m.}$$

(*iii*) In second gear,

$$V=\frac{88}{15}\times 6{\cdot}2=36{\cdot}35 \text{ km/hr.}$$

$$\therefore \quad R=0{\cdot}018\times 6350+0{\cdot}00281\times 5{\cdot}574\times(36{\cdot}35)^2$$
$$=114{\cdot}30+20{\cdot}72=135{\cdot}02 \text{ kg.}$$

Let the maximum grade the truck can climb be 1 in A,

therefore, $$R=\left(135{\cdot}02+\frac{6350}{A}\right)\text{kg.}$$

Now $$F_t=\frac{\text{b.h.p.}\times\eta_t\times 75}{V}$$

$$=\frac{85{\cdot}25\times 0{\cdot}8\times 75\times 3600}{1000\times 36{\cdot}35}=506{\cdot}5 \text{ kg.}$$

$$\therefore \quad 135{\cdot}02+\frac{6350}{A}=506{\cdot}5$$

$$\frac{6350}{A}=506{\cdot}5-135{\cdot}02=371{\cdot}48$$

$$A=\frac{6350}{371{\cdot}48}=17{\cdot}125.$$

Therefore, the maximum grade the vehicle can drive is 1 : 17·12.

(*iv*) Now the maximum pull on level $=T_d$

=Tractive effort available—Tractive effort for resistance on level

$=506{\cdot}5-135{\cdot}02=371{\cdot}48$ kg.

Problem 1·3. *Standing on a gradient of 1 in 10 with mass of 810 kg, how much distance a motor vehicle would travel in 30 seconds when hand brakes are released. Rolling resistance is 1 per cent of its mass. What is its final speed ?*

Solution. Total vertical downwards force, $W=m\times g$

$=810\times 9{\cdot}8$ N$=7938$ N

Force producing forward motion

=Gradient resistance—Rolling resistance

$$\frac{W}{g}-R_r=\frac{W}{G}-WK_r$$

$$=\frac{810\times 9{\cdot}8}{10}-\frac{810\times 9{\cdot}8}{100}\text{ N}$$

$$=793{\cdot}8-79{\cdot}38 \text{ N}$$

$$=714{\cdot}42 \text{ Newton.}$$

For calculating the final speed, the force producing motion should be converted into mass (kg). Here 9·8 N is the conversion factor of Newton to kg, we divide N by 9·8 to obtain force in terms of mass (kg.)

Now Accelerating force$=m \cdot a$.

$\therefore$ Acceleration $=F/m$

$$=\frac{714{\cdot}42 \text{ N}}{\frac{7938 \text{ (N)}}{9{\cdot}8 \text{ (m s}^2)}}$$

$$=\frac{71\ {\cdot}42\times 9{\cdot}8}{7938} \text{ m/sec}^2.$$

$$=0{\cdot}8825 \text{ m/sec}^2.$$

Let S metres be the distance travelled in 30 seconds.

$$\therefore \qquad S=\frac{1}{2}at^2$$

$$=\frac{1}{2}\times 0{\cdot}8825\times 30\times 30$$

$$=397{\cdot}5 \text{ metres.}$$

The final velocity of the vehicle is

$$S=\frac{v}{2}t$$

or $$v=\frac{2S}{t}=\frac{2\times 397{\cdot}5}{30}=26{\cdot}5 \text{ m/sec.}$$

Problem 1·4. *How far will a vehicle having a mass of 750 kg and travelling at 37·5 km/hr up a gradient 1 in 10 would travel before stopping when neutral is applied. Its rolling resistance is 155 N ?*

Solution. Total vertical downward force

$$F=750\times 9{\cdot}8=7350 \text{ N.}$$

Forces opposing the motion of the vehicle

=Gradient resistance+Rolling resistance

$$=\frac{W}{G}+WR_r=\frac{7350}{10}+155$$

$$=735+155=890 \text{ N.}$$

Retardation force $F=m.c$

$\therefore$ Retardation $a=F/m$

$$=\frac{155 \text{ N}}{7350\div(9{\cdot}8)}=\frac{155\times 9{\cdot}8}{7350}$$

$$=0{\cdot}207 \text{ m/sec}^2.$$

Now the distance travelled before stopping is given as

$$v^2-u^2=2aS$$

$$\therefore \qquad S=\frac{v^2-u^2}{2a}$$

Since $u=0$

$$\therefore \quad S=\frac{v^2}{29}=\frac{37{\cdot}5\times 37{\cdot}5\times 1000\times 1000}{3600\times 2\times 0{\cdot}207\times 3600}$$

$=$**944·75 metres.**

Problem 1·5. *The co-efficient of rolling resistance for a vehicle weighing 7500 kg is 0·015 and the co-efficient of air resistance is 0·00281 in the formula* $R=kW\times k_a AV^2$, *where A is the frontal area in m², V is the speed in km/hr. The transmission efficiency in the top gear 5 : 5 : 1 is 90% and that in the second gear 11 : 1 is 80%. The frontal area is 5·575 m². If the vehicle has to have a maximum speed of 88 km per hour in the top gear, calculate*

(*a*) *The engine b.h p. required.*

(*b*) *The engine speed of the driving wheel has an effection diameter of 9 cm.*

(*c*) *The maximum grade the vehicle can negotiate at the above engine speed in the second gear.*

(*d*) *The maximum drawbar pull available on level at the above engine speed in second gear.* (*A.M.I.E., Sec B May 1975*)

Solution. For top gear ;

$K=0{\cdot}015,\ W=7500$ kg, $k_a=0{\cdot}00281$

$A=5{\cdot}575$ m², $V=88$ km/hr.

$\therefore$ Resistance $R=kW+k_aAV^2$ kg

$$=0{\cdot}015\times 7500+0{\cdot}00281\times 5{\cdot}575\times (88)^2$$

$$=112{\cdot}5+121{\cdot}35$$

$$=233{\cdot}85 \text{ kg.}$$

(*i*) Engine b.h.p.,

$$P_e=\frac{R_r\times V}{75\times \eta_t}$$

$$=\frac{233{\cdot}85\times 88\times 1000}{75\times 0{\cdot}9\times 60\times 60}$$

$$=84{\cdot}7 \text{ h.p.}$$

(*ii*) Engine speed,

$$V=\frac{\pi dN}{Gr}$$

$$\therefore \quad N=\frac{V\,Gr}{\pi d}$$

$$=\frac{88\times 1000\times 5{\cdot}5\times 100}{3{\cdot}14\times 90\times 60}$$

$$=2845 \text{ r.p.m.}$$

(*iii*) In Second Gear

Speed, $V=\frac{88\times 5\cdot 5}{11}=44$ km/hr

$=\frac{44\times 1000}{60\times 60}=12\cdot 2$ m/sec.

∴ Resistance $R=0\cdot 015\times 7500+0\cdot 00281\times 5\cdot 575\times (44)^2$

$=112\cdot 5+30\cdot 15$

$=142\ 65$ kg.

If the maximum grade, the vehicle can climb is 1 in A

∴ $R=\left(142\cdot 65+\frac{7500}{A}\right)$kg.

Now tractive effort

$$F_t=\frac{\text{b.h.p.}\times \eta_t\times 75}{V}$$

$$=\frac{84\cdot 7\times 0\cdot 8\times 75}{12\cdot 2}=416\cdot 55 \text{ kg.}$$

Now Tractive resistance = Tractive effort

or $R=F_t$

or $142\cdot 65+\frac{7500}{A}=416\cdot 55$

or $\frac{7500}{A}=416\cdot 55-142\cdot 65=273\cdot 9$

or $A=\frac{7500}{273\cdot 9}=27\cdot 4.$

∴ Maximum grade is 1 in 27·4.

(*iv*) Maximum pull in level

T_d = Tractive effort available − Tractive effort for resistance on level

$=416\cdot 55-142\cdot 65=273\cdot 9$ kg.

IMPORTANT QUESTIONS

1. (*a*) What are the various resistance to motion of a vehicle ? How do they effect power ?

(*b*) A car of gross weight W kg and frontal area A square metres, climbs a road of grade G per cent at a speed of U kilometre per hour. Find out the road load power required to propel the car, accounting for rolling and air resistance and road grade.

(*A.M.I.E. Sec. B, May 1975*)

2. Write short notes on :

(*a*) The advantage and disadvantage of the forked and articulated connecting rod.

(*b*) The functioning of an over-sized engine at sea level and at high altitude. (*May 1963*)

3. Explain rolling resistance encountered due to motion of a vehicle.

Explain one method of determining rolling resistance experimetally.

Calculate b.h.p. for a speed of 90 km.p.h. for a vehicle having a rolling resistance given by the expression $35+0{\cdot}25\ V$ and air resistance by $0{\cdot}048V^2$ (resistance being in kg and V the speed in km.p.h. in each case). The transmission efficiency is 85%.

(*Nov. 1964*)

4. A motor vehicle total weight 2,500 kg has a road wheels of 24 cm effective dia. The effective moment of inertia of the four road wheels and the rear axle together is 150 kg-m², while that of the engine and the flywheel is 15 kg-m². The transmission efficiency is 90% and tractive resistance at a speed of 15 km.p.h. is 50 kg. The total available engine torque is 150 kg-m.

(*a*) Determine the gear ratio, engine to back axle to provide maximum acceleration on 1 in 4 up grade, when travelling at 15 km.p.h.

(*b*) What is the maximum acceleration.

(*c*) Determine the engine r.p.m. and H.P. under these conditions. (*May 1965*)

[Ans. 19·915 ; 1 ; 2·47 m/sec² ; 4150 r.p.m., 120 h.p.]

5. A motor vehicle weighs 0·8 ton (0·813 tonnes) and its engine develops 20 h.p. (20·28 c.v.) at 2800 r.p.m. At this engine speed the road speed of the car on the top gear is 40 miles/hr and the efficiency of transmission is 88% on top and 80% on bottom gear. The diameter of types is 30″ (0·762 m) and the projected front area of the vehicle is 12 sq ft. (1·116 sq m). The coefficient of air resistance is 0·0017 lb/sq. ft/miles per hour square, *i.e.* $R=kAV^2$, where R is resistance in lb, k is co-efficient of resistance. A is the front area in sq/ft., V is speed in miles/hr. Road resistance is 50 lb/ton (0·023 kg/kg).

Calculate :

(*a*) Speed of the car on bottom gear.

(*b*) Tractive effort available at the wheels on top and bottom gear.

(*c*) Gradient which car can climb on bottom gear.

(*d*) The tractive force at the wheels require to start up the car on the level and attain a speed of 30 m.p.h. (48·28 km/hr) in 40 sec. (Average air resistance may be taken as half the maximum and accelerating force to vanish at 30 miles/hr speed). (*May 1966*)

[**Ans.** 18·4 km/hr ; 73·85 kgf ; 234·7 kgf ; 1 in 3·648 ; 133·85 kgf]

6. A passenger car weights 3,000 lb (1360·8 kg). The rolling resistance may be assumed as 10 lb (4·536 kg) per 1000 lb (453·6 kg) of vehicle weight. The air resistance is given by 0·00017 AV^2, where A=frontal area sq ft and V=car speed m.p.h. If the frontal area of the vehicle is 25 sq ft (2·312 sq m) and if the car speed is 30 m.p.h. (48·27 km/hr).

(*i*) Determine the power required to propel the vehicle on level road.

(*ii*) If the tractive effort available at the wheels is 418 lb (189·604 kg), find the maximum gradient which the vehicle can climb. (*May 1967*)

7. A motor car weighs 35,000 lb (1587·6 kg) gross weight and has a wheel base of 10·5 ft (3·2 m) and its centre of gravity is 4·25 ft (1·295 m) in front of the rear axle and is 3 ft (0·914 m) above ground level. Co-efficient of friction between tyre and road surface is 0·6 and brakes are supplied to rear wheels only.

(*a*) Calculate the weight carried by the front axle and the rear axle during brakes application, for maximum retardation.

(*b*) Determine the maximum retardation (rear brakes applied).

(*c*) What is the maximum stopping distance while travelling at 20 m.p.h. (32·186 km/hr), when only rear brakes are applied ? (*May 1967*)

8. The weight of the given passenger car is 2,500 lb (1·134 kg) including that of four wheels. Each wheel weighs 50 lb (22 68 kg) and has radius or gyration of 12" (304·8 mm) and effective radius of wheels is 13" (330·2 mm).

The car is powered by an engine, which develops a B.H.P. of 50 at 3,003 r.p.m. and the components revolving at engine speed weigh 125 lb (56·7 kg) with a radius of gyration of 35" (88·9 mm). The sum of air and rolling resistance on level road may be assumed as 178 lb (80 kg), transmission efficiency in top gear=90% and two gear ratio=4·2 : 1.

Calculate the vehicle acceleration in kg/sec/sec considering the effect of revolving components. (*Nov. 1967*)

9. A car of gross weight 3,000 lb (1360·8 kg) is fitted with shoe type brakes on all four wheels, and is retarded uniformly from 0 m p.h. (96·54 km/hr) to 30 m.p.h. (48·27 km/hr) in a distance of 1,500 ft (457·2 m) while on level road. Assuming uniform distribut ion of braking forces, calculate the heat generated at each wheel in B.T.U. during brake application. Also find the mean lining pressure (p.s.i.) from the data given below :

Effective wheel diameter=28" (711 mm)

Dia of brake drum =12·5" (318 mm).

Width of brake lining =2" (50·8 mm).

Total angle of contact of lining with each brake drum=210°.

Coefficient of friction between brake lining and drum=0·3.

The effective radius of frictional force may be assumed as equal to effective radius of wheel. Lining are symmetrical.

(*Nov. 1967*)

10. A passenger car travelling at 50 m.p.h. (80·45 km.p.h.) is accelerated up a gradient of 1 in 20. The gross vehicle weight is 2,500 lb (1,124 kg). It has a frontal area of sq. ft (1·858 sq m) and the air resistance coefficient may be assumed as 0·0017. The rolling resistance is 50 lb (22·6 kg). At the above vehicle speed, the engine develops 80 B.H.P. corresponding to an engine speed of 4,400 r.p.m. Rear axle ratio=5 : 1 ; efficiency=95%. Calculate (*a*) the total tractive resistance, (*b*) the tractive efforts available at the wheels, and (*c*) acceleration while ascending the above gradient.

(*May 1968*)

11. A car with passenger weighing 2,700 lb (1,224·7 kg) and having a frontal area of 24 sq ft (2·24 sq m) has to run on a level road at a maximum speed of 75 m.p.h. (120 km/hr). Rolling resistance for this car is 40 lb/ton of car weight (17·65 kg per 1000 kg) and wind resistance coefficient is 0·0015 (0·0028). Transmission efficiency at top gear may be taken as 90%.

The same has to climb a hill with a maximum gradient of 35% (*i.e.* 35 ft rise in a horizontal distance of 100 ft) at 10 m.p.h. (16 km per hr) and has a first gear ratio of 28 : 1. The transmission efficiency at first gear may be taken as 80%. Find out

(*a*) B.H.P. of the engine at a maximum speed of car.

(*b*) Engine r.p.m. at maximum speed of car.

(*c*) Torque exerted by the engine when the car is going up the gradient.

(*d*) Engine r.p.m. when the car is going up the gradient. The car has a rear axle ratio of 5 : 1 and wheel radius of 14" (35·5 cm).

(*Nov. 1969*)

12. (*a*) What are various resistances to motion of a vehicle ? How do they effect power. Explain how power required by a vehicle while climbing a slope its calculated.

(*A.M.I.E. June 1975, 76, Summer 1986*)

(*b*) A car of gross weight W kg and frontal area Am^2, climbs a road of grade G per cent at a speed of V km/hr. Find out the road load power required to propel the car accounting the rating and our resistances and road grade. (*A.M.I.E., June 1975*)

13. With the help of a suitable layout diagram explain clearly, however power is transmitted from the engine to wheels in a 'four wheel drive' vehicle.

Name each of these units in the chassis and explain clearly their functions. (*A.M.I.E. Nov. 1969*)

14. Show the different types of chassis layouts that are in use for cars and transport vehicles, explaining how power is transmitted from the engine to the driving wheels. Explain the advantages of each of these layout. (*A.M.I.E. Nov. 1970*)

15. Say true or false :

(*a*) An engine coupled to a water pump on a trolley is an automobile.

(*b*) A Jeep is two × six wheels drive.

(*c*) Three wheelers Tempos have rear wheel drive.

(*d*) A pattern tank is an automobile.

(*e*) Lambretta has a powering engine.

(*f*) The frame of a jeep can be replaced.

(*g*) Fuel pump is situated at the bottom of the engine.

(*h*) It is possible to place an engine with its axis parallel to front axle.

16. Show by line diagram how the drive is taken from the engine to the driving wheels for the following arrangements and explain clearly the advantages and disadvantages of each arrangement :

(*a*) Front engine rear wheel drive.

(*b*) Front engine front wheel drive.

(*c*) Front engine four wheel drive.

(*d*) Rear engine rear wheel drive. (*A.M.I.E. Sec. B. May 1974*)

17. Sketch the layout of a car with from, mounted engine is which the drive is received by rear wheels. What are the advantages and limitation of this method ? (*A.M.I.E. Sec. B, Dec. 1975*)

18. The co-efficient of rolling resistance for a vehicle weighing 7500 kg is 0·015 and the co-efficient of air resistance is 0·00281 in the formula $R=kW+K_a.\ AV^2$, where A is the frontal area in m^2 and V is the speed in km/hr. The transmission efficiency in the top gear 5·5 : 1 is 90% and that in the second gear 11 : 1 is 80%. The frontal area is 5·575 m². If the vehicle has to have a maximum speed of 88 km per hour in the top gear. Calculate (*a*) The engine b.h.p. required. (*b*) The engine speed if the driving wheel has an effective diameter of 90 cm. (*c*) The maximum grade the truck can negotiate at the above engine speed in second gear. (*d*) The maximum drawbar pull available on level at the above engine speed in second gear. (*A.M.I.E. Sec. B, Way 1975*)

19. Find the h.p. of a Fiat car weighing 1150 kg including 4 passengers, luggage, fuel, lubricating oil and cooling system. Engine is running in top gear at 5000 r.p m. Size of wheel tyre is 0·508 metre. Crown wheel to pinion ratio=4·3 : 1.

Frontal area of body=2·2 square metres. Take coefficient of rolling friction and air friction as 0·012 and 0·0007 respectively. (*A.M.I.E. Sec. B, May 1975*)

20. Give the constructional features of an Indian bus. (*S.B.T.E. May 1978*)

21. Describe how power is transmitted from the engine to wheels of a motor vehicle. (*S.B.T.E. May 1978*)

Explain the function of main units involved. (*S.B.T.E. June, 1980*)

22. (*a*) Discuss the layout of power plant in different types of automotive vehicles.

(*b*) Discuss the working principles of air cushion vehicles. (*A.M.I.E Sec. B., May 1977*)

23. (*a*) How are the motor vehicles classified. (*A.M.I.E. Sec B, Winter 1986*)

(*b*) Classify types of automotive vehicles and discuss the special features of rough terrain vehicles. (*A.M.I.E. Sec B, Summer 1982*)