1

Tire and Rim Fundamentals

We introduce and review some topics about tires, wheels, roads, vehicles, and their interactions. These subjects are needed to understand vehicle dynamics better.

1.1 Tires and Sidewall Information

Pneumatic tires are the only means to transfer forces between the road and the vehicle. Tires are required to produce the forces necessary to control the vehicle, and hence, they are an important component of a vehicle.

Figure 1.1 illustrates a cross section view of a tire on a rim to show the dimension parameters that are used to standard tires.

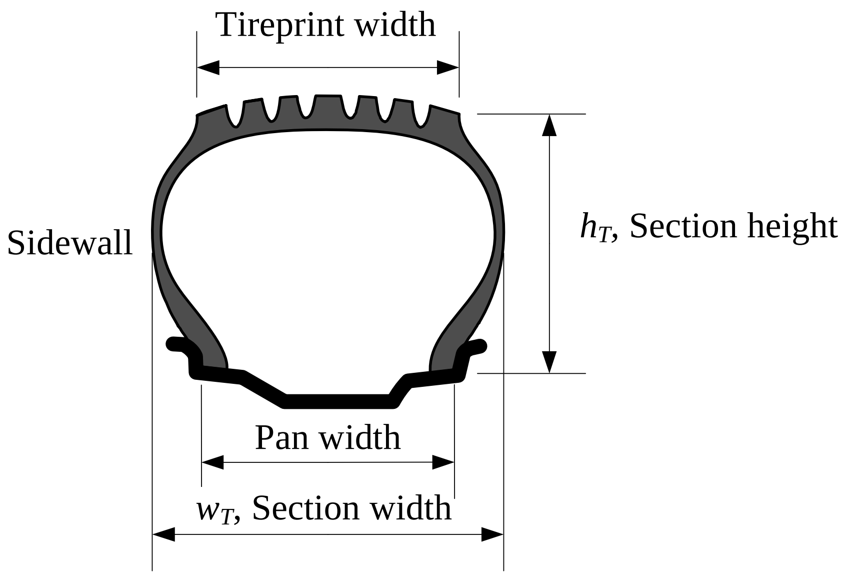

FIGURE 1.1. Cross section of a tire on a rim to show tire height and width.

The *section height*, *tire height*, or simply *height*, h_T, is a number that must be added to the rim radius to make the wheel radius. The *section width*, or *tire width*, w_T, is the widest dimension of a tire when the tire is not loaded.

Tires are required to have certain information printed on the tire *sidewall*. Figure 1.2 illustrates a side view of a sample tire to show the important information printed on a tire sidewall.

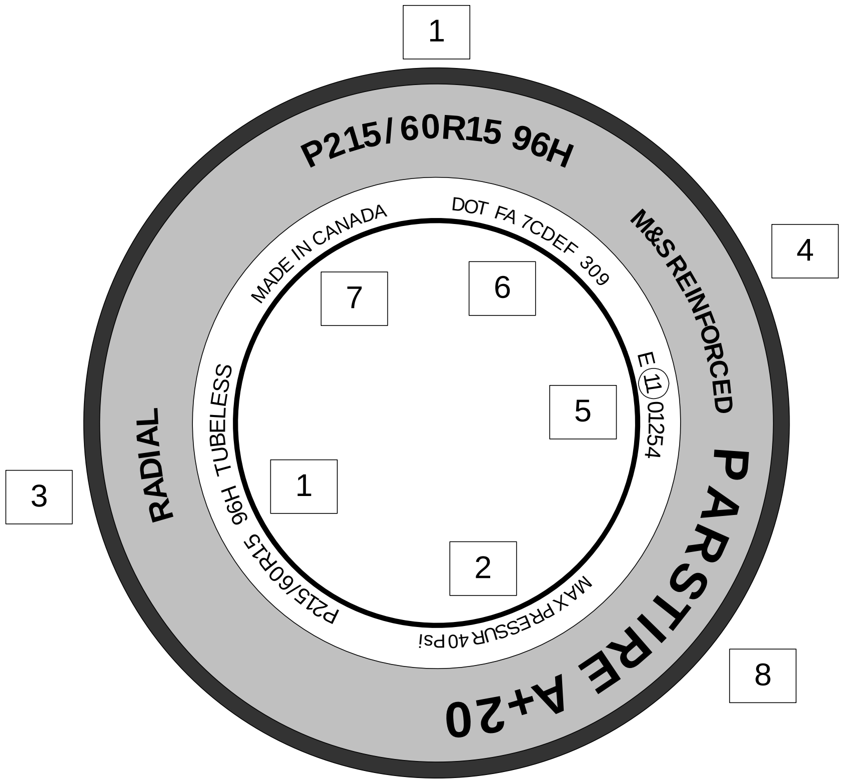

FIGURE 1.2. Side view of a tire and the most important information printed on a tire sidewall.

The codes in Figure 1.2 are:

$\boxed{1}$ Size number.
$\boxed{2}$ Maximum allowed inflation pressure.
$\boxed{3}$ Type of tire construction.
$\boxed{4}$ M&S denotes a tire for mud and snow.
$\boxed{5}$ E-Mark is the Europe type approval mark and number.
$\boxed{6}$ US Department of Transport (DOT) identification numbers.
$\boxed{7}$ Country of manufacture.
$\boxed{8}$ Manufacturers, brand name, or commercial name.

The most important information on the sidewall of a tire is the *size number*, indicated by $\boxed{1}$. To see the format of the size number, an example is shown in Figure 1.3 and their definitions are explained as follows.

$\boxed{P}$ *Tire type.* The first letter indicates the proper type of car that the tire is made for. $\boxed{P}$ stands for passenger car. The first letter can also be $\boxed{ST}$ for special trailer, $\boxed{T}$ for temporary, and $\boxed{LT}$ for light truck.

$\boxed{215}$ *Tire width.* This three-number code is the width of the unloaded tire from sidewall to sidewall measured in [mm].

P 215 / 60 R 15 96 H

P	Passenger car
215	Tire width [mm]
60	Aspect ratio [%]
R	Radial
15	Rim diameter [in]
96	Load rating
H	Speed rating

FIGURE 1.3. A sample of a tire size number and its meaning.

$\boxed{60}$ *Aspect ratio.* This two-number code is the ratio of the tire section height to tire width, expressed as a percentage. Aspect ratio is shown by s_T.

$$s_T = \frac{h_T}{w_T} \times 100 \tag{1.1}$$

Generally speaking, tire aspect ratios range from 35, for race car tires, to 75 for tires used on utility vehicles.

$\boxed{R}$ *Tire construction type.* The letter $\boxed{R}$ indicates that the tire has a radial construction. It may also be $\boxed{B}$ for bias belt or bias ply, and $\boxed{D}$ for diagonal.

$\boxed{15}$ *Rim diameter.* This is a number in [in] to indicate diameter of the rim that the tire is designed to fit on.

$\boxed{96}$ *Load rate or load index.* Many tires come with a service description at the end of the tire size. The service description is made of a two-digit number (load index) and a letter (speed rating). The load index is a representation of the maximum load each tire is designed to support.

Table 1.1 shows some of the most common load indices and their load-carrying capacities. The load index is generally valid for speeds under $210\,\mathrm{km/h}$ ($\approx 130\,\mathrm{mi/h}$).

$\boxed{H}$ *Speed rate.* Speed rate indicates the maximum speed that the tire can sustain for a ten minute endurance without breaking down.

Table 1.2 shows the most common speed rate indices and their meanings.

Example 1 *Weight of a car and load index of its tire.*

For a car that weighs $2\,\mathrm{tons} = 2000\,\mathrm{kg}$*, we need a tire with a load index higher than* 84*. This is because we have about* $500\,\mathrm{kg}$ *per tire and it is in a load index of* 84*.*

Table 1.1 - Maximum load-carrying capacity tire index.

Index	Maximum load	Index	Maximum load
0	$45\,\mathrm{kg} \approx 99\,\mathrm{lbf}$		
$\cdots$	$\cdots$	100	$800\,\mathrm{kg} \approx 1764\,\mathrm{lbf}$
71	$345\,\mathrm{kg} \approx 761\,\mathrm{lbf}$	101	$825\,\mathrm{kg} \approx 1819\,\mathrm{lbf}$
72	$355\,\mathrm{kg} \approx 783\,\mathrm{lbf}$	102	$850\,\mathrm{kg} \approx 1874\,\mathrm{lbf}$
73	$365\,\mathrm{kg} \approx 805\,\mathrm{lbf}$	103	$875\,\mathrm{kg} \approx 1929\,\mathrm{lbf}$
74	$375\,\mathrm{kg} \approx 827\,\mathrm{lbf}$	104	$900\,\mathrm{kg} \approx 1984\,\mathrm{lbf}$
75	$387\,\mathrm{kg} \approx 853\,\mathrm{lbf}$	105	$925\,\mathrm{kg} \approx 2039\,\mathrm{lbf}$
76	$400\,\mathrm{kg} \approx 882\,\mathrm{lbf}$	106	$950\,\mathrm{kg} \approx 2094\,\mathrm{lbf}$
77	$412\,\mathrm{kg} \approx 908\,\mathrm{lbf}$	107	$975\,\mathrm{kg} \approx 2149\,\mathrm{lbf}$
78	$425\,\mathrm{kg} \approx 937\,\mathrm{lbf}$	108	$1000\,\mathrm{kg} \approx 2205\,\mathrm{lbf}$
79	$437\,\mathrm{kg} \approx 963\,\mathrm{lbf}$	109	$1030\,\mathrm{kg} \approx 2271\,\mathrm{lbf}$
80	$450\,\mathrm{kg} \approx 992\,\mathrm{lbf}$	110	$1060\,\mathrm{kg} \approx 2337\,\mathrm{lbf}$
81	$462\,\mathrm{kg} \approx 1019\,\mathrm{lbf}$	111	$1090\,\mathrm{kg} \approx 2403\,\mathrm{lbf}$
82	$475\,\mathrm{kg} \approx 1047\,\mathrm{lbf}$	113	$1120\,\mathrm{kg} \approx 2469\,\mathrm{lbf}$
83	$487\,\mathrm{kg} \approx 1074\,\mathrm{lbf}$	113	$1150\,\mathrm{kg} \approx 2581\,\mathrm{lbf}$
84	$500\,\mathrm{kg} \approx 1102\,\mathrm{lbf}$	114	$1180\,\mathrm{kg} \approx 2601\,\mathrm{lbf}$
85	$515\,\mathrm{kg} \approx 1135\,\mathrm{lbf}$	115	$1215\,\mathrm{kg} \approx 2679\,\mathrm{lbf}$
86	$530\,\mathrm{kg} \approx 1163\,\mathrm{lbf}$	116	$1250\,\mathrm{kg} \approx 2806\,\mathrm{lbf}$
87	$545\,\mathrm{kg} \approx 1201\,\mathrm{lbf}$	117	$1285\,\mathrm{kg} \approx 2833\,\mathrm{lbf}$
88	$560\,\mathrm{kg} \approx 1235\,\mathrm{lbf}$	118	$1320\,\mathrm{kg} \approx 2910\,\mathrm{lbf}$
89	$580\,\mathrm{kg} \approx 1279\,\mathrm{lbf}$	119	$1360\,\mathrm{kg} \approx 3074\,\mathrm{lbf}$
90	$600\,\mathrm{kg} \approx 1323\,\mathrm{lbf}$	120	$1400\,\mathrm{kg} \approx 3086\,\mathrm{lbf}$
91	$615\,\mathrm{kg} \approx 1356\,\mathrm{lbf}$	121	$1450\,\mathrm{kg} \approx 3197\,\mathrm{lbf}$
92	$630\,\mathrm{kg} \approx 1389\,\mathrm{lbf}$	122	$1500\,\mathrm{kg} \approx 3368\,\mathrm{lbf}$
93	$650\,\mathrm{kg} \approx 1433\,\mathrm{lbf}$	123	$1550\,\mathrm{kg} \approx 3417\,\mathrm{lbf}$
94	$670\,\mathrm{kg} \approx 1477\,\mathrm{lbf}$	124	$1600\,\mathrm{kg} \approx 3527\,\mathrm{lbf}$
95	$690\,\mathrm{kg} \approx 1521\,\mathrm{lbf}$	125	$1650\,\mathrm{kg} \approx 3690\,\mathrm{lbf}$
96	$710\,\mathrm{kg} \approx 1565\,\mathrm{lbf}$	126	$1700\,\mathrm{kg} \approx 3748\,\mathrm{lbf}$
97	$730\,\mathrm{kg} \approx 1609\,\mathrm{lbf}$	127	$1750\,\mathrm{kg} \approx 3858\,\mathrm{lbf}$
98	$750\,\mathrm{kg} \approx 1653\,\mathrm{lbf}$	128	$1800\,\mathrm{kg} \approx 3968\,\mathrm{lbf}$
99	$775\,\mathrm{kg} \approx 1709\,\mathrm{lbf}$	$\cdots$	$\cdots$
		199	$13600\,\mathrm{kg} \approx 30000\,\mathrm{lbf}$

Example 2 *Height of a tire based on tire numbers.*

A tire has the size number $P215/60R15$ $96H$. The aspect ratio 60 *means the height of the tire is equal to* 60% *of the tire width. To calculate the tire height in* [mm], *we should multiply the first number* (215) *by the second number* (60) *and divide by* 100.

$$h_T = 215 \times \frac{60}{100} = 129\,\mathrm{mm} \tag{1.2}$$

This is the tire height from rim to tread.

Table 1.2 - Maximum speed tire index.

Index	Maximum speed	Index	Maximum speed
B	$50\,\mathrm{km/h} \approx 31\,\mathrm{mi/h}$	P	$150\,\mathrm{km/h} \approx 93\,\mathrm{mi/h}$
C	$60\,\mathrm{km/h} \approx 37\,\mathrm{mi/h}$	Q	$160\,\mathrm{km/h} \approx 100\,\mathrm{mi/h}$
D	$65\,\mathrm{km/h} \approx 40\,\mathrm{mi/h}$	R	$170\,\mathrm{km/h} \approx 106\,\mathrm{mi/h}$
E	$70\,\mathrm{km/h} \approx 43\,\mathrm{mi/h}$	S	$180\,\mathrm{km/h} \approx 112\,\mathrm{mi/h}$
F	$80\,\mathrm{km/h} \approx 50\,\mathrm{mi/h}$	T	$190\,\mathrm{km/h} \approx 118\,\mathrm{mi/h}$
G	$90\,\mathrm{km/h} \approx 56\,\mathrm{mi/h}$	U	$200\,\mathrm{km/h} \approx 124\,\mathrm{mi/h}$
J	$100\,\mathrm{km/h} \approx 62\,\mathrm{mi/h}$	H	$210\,\mathrm{km/h} \approx 130\,\mathrm{mi/h}$
K	$110\,\mathrm{km/h} \approx 68\,\mathrm{mi/h}$	V	$240\,\mathrm{km/h} \approx 150\,\mathrm{mi/h}$
L	$120\,\mathrm{km/h} \approx 75\,\mathrm{mi/h}$	W	$270\,\mathrm{km/h} \approx 168\,\mathrm{mi/h}$
M	$130\,\mathrm{km/h} \approx 81\,\mathrm{mi/h}$	Y	$300\,\mathrm{km/h} \approx 188\,\mathrm{mi/h}$
N	$140\,\mathrm{km/h} \approx 87\,\mathrm{mi/h}$	Z	$+240\,\mathrm{km/h} \approx +149\,\mathrm{mi/h}$

Example 3 *Alternative tire size indication.*

If the load index is not indicated on the tire, then a tire with a size number such as $255/50R17\ 100V$ *may also be numbered by* $255/50VR17$.

Example 4 *Tire and rim widths.*

The dimensions of a tire are dependent on the rim on which it is mounted. For tires with an aspect ratio of 50 *and above, the rim width is approximately* 70% *of the tire's width, rounded to the nearest* $0.5\,\mathrm{in}$. *As an example, a* $P255/50R16$ *tire has a design width of* $255\,\mathrm{mm} = 10.04\,\mathrm{in}$ *however,* 70% *of* $10.04\,\mathrm{in}$ *is* $7.028\,\mathrm{in}$, *which rounded to the nearest* $0.5\,\mathrm{in}$, *is* $7\,\mathrm{in}$. *Therefore, a* $P255/50R16$ *tire should be mounted on a* 7×16 *rim.*

For tires with aspect ratio 45 *and below, the rim width is* 85% *of the tire's section width, rounded to the nearest* $0.5\,\mathrm{in}$. *For example, a* $P255/45R17$ *tire with a section width of* $255\,\mathrm{mm} = 10.04\,\mathrm{in}$, *needs an* $8.5\,\mathrm{in}$ *rim because* 85% *of* $10.04\,\mathrm{in}$ *is* $8.534\,\mathrm{in} \approx 8.5\,\mathrm{in}$. *Therefore, a* $P255/45R17$ *tire should be mounted on an* $8\frac{1}{2} \times 17$ *rim.*

Example 5 *Calculating tire diameter and radius.*

We are able to calculate the overall diameter of a tire using the tire size numbers. By multiplying the tire width and the aspect ratio, we get the tire height. As an example, we use tire number $P235/75R15$.

$$\begin{aligned} h_T &= 235 \times 75\% \\ &= 176.25\,\mathrm{mm} \approx 6.94\,\mathrm{in} \end{aligned} \tag{1.3}$$

Then, we add twice the tire height h_T *to the rim diameter to determine the* *tire's unloaded diameter $D = 2R$ and radius R.*

$$\begin{aligned} D &= 2 \times 6.94 + 15 \\ &= 28.88\,\mathrm{in} \approx 733.8\,\mathrm{mm} \qquad (1.4) \\ R &= D/2 = 366.9\,\mathrm{mm} \qquad (1.5) \end{aligned}$$

Example 6 *Speed rating code.*

Two similar tires are coded as $P235/70HR15$ and $P235/70R15$ $100H$. Both tires have code $H \equiv 210\,\mathrm{km/h}$ for speed rating. However, the second tire can sustain the coded speed only when it is loaded less than the specified load index, so it states $100H \equiv 800\,\mathrm{kg}\,210\,\mathrm{km/h}$.

Speed ratings generally depend on the type of tire. Off road vehicles usually use Q-rated tires, passenger cars usually use R-rated tires for typical street cars or T-rated for performance cars.

Example 7 *Tire weight.*

The average weight of a tire for passenger cars is $10 - 12\,\mathrm{kg}$. The weight of a tire for light trucks is $14 - 16\,\mathrm{kg}$, and the average weight of commercial truck tires is $135 - 180\,\mathrm{kg}$.

Example 8 *Effects of aspect ratio.*

A higher aspect ratio provides a softer ride and an increase in deflection under the load of the vehicle. However, lower aspect ratio tires are normally used for higher performance vehicles. They have a wider road contact area and a faster response. This results in less deflection under load, causing a rougher ride to the vehicle.

Changing to a tire with a different aspect ratio will result in a different contact area, therefore changing the load capacity of the tire.

Example 9 ★ *BMW tire size code.*

BMW, a European car, uses the metric system for sizing its tires. As an example, $TD230/55ZR390$ is a metric tire size code. TD indicates the BMW TD model, 230 is the section width in [mm], 55 is the aspect ratio in percent, Z is the speed rating, R means radial, and 390 is the rim diameter in [mm].

Example 10 ★ *"MS," "$M + S$," "M/S," and "$M\&S$" signs.*

The sign "MS,"and "$M + S$," and "M/S," and "$M\&S$" indicate that the tire has some mud and snow capability. Most radial tires have one of these signs.

Example 11 ★ *U.S. DOT tire identification number.*

The US tire identification number is in the format "$DOT\ DNZE\ ABCD$ 1309." It begins with the letters DOT to indicate that the tire meets US federal standards. DOT stands for Department of Transportation. The next two characters, DN, after DOT is the plant code, which refers to the manufacturer and the factory location at which the tire was made.

The next two characters, ZE*, are a letter-number combination that refers to the specific mold used for forming the tire. It is an internal factory code and is not usually a useful code for customers.*

The last four numbers, 1309*, represents the week and year the tire was built. The other numbers,* $ABCD$*, are marketing codes used by the manufacturer or at the manufacturer's instruction. An example is shown in Figure 1.4.*

DOT DNZE ABCD 1309

FIGURE 1.4. An example of a US DOT tire identification number.

DN *is the plant code for Goodyear-Dunlop Tire located in Wittlich, Germany.* ZE *is the tire's mold size,* $ABCD$ *is the compound structure code,* 13 *indicates the* 13*th week of the year, and* 09 *indicates year* 2009*. So, the tire is manufactured in the* 13*th week of* 2009 *at Goodyear-Dunlop Tire in Wittlich, Germany.*

Example 12 ★ *Canadian tires identification number.*

In Canada, all tires should have an identification number on the sidewall. An example is shown in Figure 1.5.

DOT B3CD E52X 2112 

FIGURE 1.5. An example of a Canadian DOT tire identification number.

This identification number provides the manufacturer, time, and place that the tire was made. The first two characters following DOT *indicate the manufacturer and plant code. In this case,* $B3$ *indicates Group Michelin located at Bridgewater, Nova Scotia, Canada. The third and fourth characters,* CD*, are the tire's mold size code. The fifth, sixth, seventh, and eighth characters,* $E52X$*, are optional and are used by the manufacturer. The final four numbers,* 2112*, indicates the manufacturing date. For example,* 2112 *indicate the twenty first week of year* 2012*. Finally, the maple leaf sign or the flag sign following the identification number indicates that the tire is manufactured in Canada. It also certifies that the tire meets Transport Canada requirements.*

Example 13 ★ *E-Mark and international codes.*

All tires sold in Europe after July 1997 *must carry an E-mark. An example is shown by* $\boxed{5}$ *in Figure 1.2. The mark itself is either an upper or lower case "E" followed by a number in a circle or rectangle, followed by a further number. An "E" indicates that the tire is certified to comply with the dimensional, performance and marking requirements of* ECE

regulation. ECE or $UNECE$ stands for the united nations economic commission for Europe. The number in the circle or rectangle is the country code. Example: 11 *is the* UK. *The first two digits outside the circle or rectangle indicate the regulation series under which the tire was approved. Example:* "02" *is for* ECE *regulation* 30 *governing passenger tires, and* "00" *is for* ECE *regulation* 54 *governing commercial vehicle tires. The remaining numbers represent the* ECE *mark type approval numbers. Tires may have also been tested and met the required noise limits. These tires may have a second* ECE *branding followed by an* "$-s$" *for sound.*

Table 1.3 *indicates the European country codes for tire manufacturing.*

Besides the DOT and ECE *codes for US and Europe, we may also see the other country codes such as:* $ISO-9001$ *for international standards organization, C.C.C for China compulsory product certification,* $JIS\,D\,4230$ *for Japanese industrial standard.*

Table 1.3 - *European county codes for tire manufacturing.*

Code	*Country*	*Code*	*Country*
$E1$	*Germany*	$E14$	*Switzerland*
$E2$	*France*	$E15$	*Norway*
$E3$	*Italy*	$E16$	*Finland*
$E4$	*Netherlands*	$E17$	*Denmark*
$E5$	*Sweden*	$E18$	*Romania*
$E6$	*Belgium*	$E19$	*Poland*
$E7$	*Hungary*	$E20$	*Portugal*
$E8$	*Czech Republic*	$E21$	*Russia*
$E9$	*Spain*	$E22$	*Greece*
$E10$	*Yugoslavia*	$E23$	*Ireland*
$E11$	*United Kingdom*	$E24$	*Croatia*
$E12$	*Austria*	$E25$	*Slovenia*
$E13$	*Luxembourg*	$E26$	*Slovakia*

Example 14 ★ *Light truck tires.*

The tire sizes for a light truck may be shown in two formats:

$$LT245/70R16$$

or

$$32 \times 11.50R16LT$$

In the first format, LT ≡*light truck,* 245 ≡*tire width in millimeters,* 70 ≡*aspect ratio in percent, R* ≡*radial structure, and* 16 ≡*rim diameter in inches.*

In the second format, 32 ≡*tire diameter in inches,* 11.50 ≡*tire width in inches, R* ≡*radial structure,* 16 ≡*rim diameter in inches, and LT* ≡*light truck.*

Example 15 ★ *UTQG ratings.*

Tire manufacturers may put some other symbols, numbers, and letters on their tires supposedly rating their products for wear, wet traction, and heat resistance. These characters are referred to as UTQG (Uniform Tire Quality Grading), although there is no uniformity and standard in how they appear. There is an index for wear to show the average wearing life time in mileage. The higher the wear number, the longer the tire lifetime. An index of 100 *is equivalent to approximately* 20000 *miles or* 30000 km. *Other numbers are indicated in Table* 1.4.

Table 1.4 *- Tread wear rating index.*

Index	*Life (Approximate)*	
100	32000 km	20000 mi
150	48000 km	30000 mi
200	64000 km	40000 mi
250	80000 km	50000 mi
300	96000 km	60000 mi
400	129000 km	80000 mi
500	161000 km	100000 mi

The UTQG also rates tires for wet traction and heat resistance. These are rated in letters between "A" to "C," where "A" is the best, "B" is intermediate and "C" is acceptable. An "A" wet traction rating is typically an indication that the tire has a deep open tread pattern with lots of sipping, which are the fine lines in the tread blocks.

An "A" heat resistance rating indicates two things: First, low rolling resistance due to stiffer tread belts, stiffer sidewalls, or harder compounds; second, thinner sidewalls, more stable blocks in the tread pattern. Temperature rating is also indicated by a letter between "A" to "CM," where "A" is the best, "B" is intermediate, and "C" is acceptable.

There might also be a traction rating to indicate how well a tire grips the road surface. This is an overall rating for both dry and wet conditions. Tires are rated as: "AA" for the best, "A" for better, "B" for good, and "C" for acceptable.

Example 16 ★ *Tire sidewall additional marks.*

$TL \equiv$ *Tubeless*

$TT \equiv$ *Tube type, tire with an inner-tube*

Made in Country $\equiv$ *Name of the manufacturing country*

$C \equiv$ *Commercial tires made for commercial trucks; Example:* $185R14C$

$B \equiv$ *Bias ply*

$SFI \equiv$ *Side facing inwards*

$SFO \equiv$ *Side facing outwards*

$TWI \equiv$ *Tire wear index*

It is an indicator in the main tire profile, which shows when the tire is worn down and needs to be replaced.

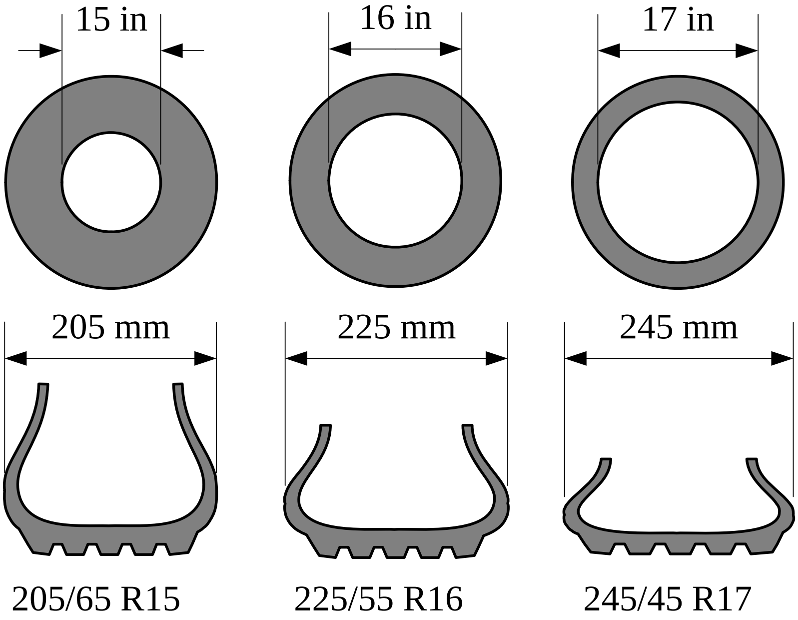

FIGURE 1.6. The plus one (+1) concept is a rule to find the tire to a rim with a 1 inch increase in diameter.

$SL \equiv$ Standard load; Tire for normal usage and loads
$XL \equiv$ Extra load; Tire for heavy loads
$rf \equiv$ Reinforced tires
$Arrow \equiv$ Direction of rotation
Some tread patterns are designed to perform better when driven in a specific direction. Such tires will have an arrow showing which way the tire should rotate when the vehicle is moving forwards.

Example 17 ★ *Plus one* (+1) *concept.*

The plus one (+1) *concept describes the sizing up of a rim and matching it to a proper tire. Generally speaking, each time we add* 1 in *to the rim diameter, we should add* 20 mm *to the tire width and subtract* 10% *from the aspect ratio. This compensates the increases in rim width and diameter, and provides the same overall tire radius. Figure 1.6 illustrates the idea.*

By using a tire with a shorter sidewall, we get a quicker steering response and better lateral stability. However, we will have a stiffer ride.

Example 18 ★ *Under- and over-inflated tire.*

Overheat caused by improper inflation of tires is a common tire failure. An under-inflated tire will support less of the vehicle weight with the air pressure in the tire; therefore, more of the vehicle weight will be supported by the tire. This tire load increase causes the tire to have a larger tireprint that creates more friction and more heat.

In an over-inflated tire, too much of the vehicle weight is supported by the tire air pressure. The vehicle will be bouncy and hard to steer because the tireprint is small and only the center portion of the tireprint is contacting

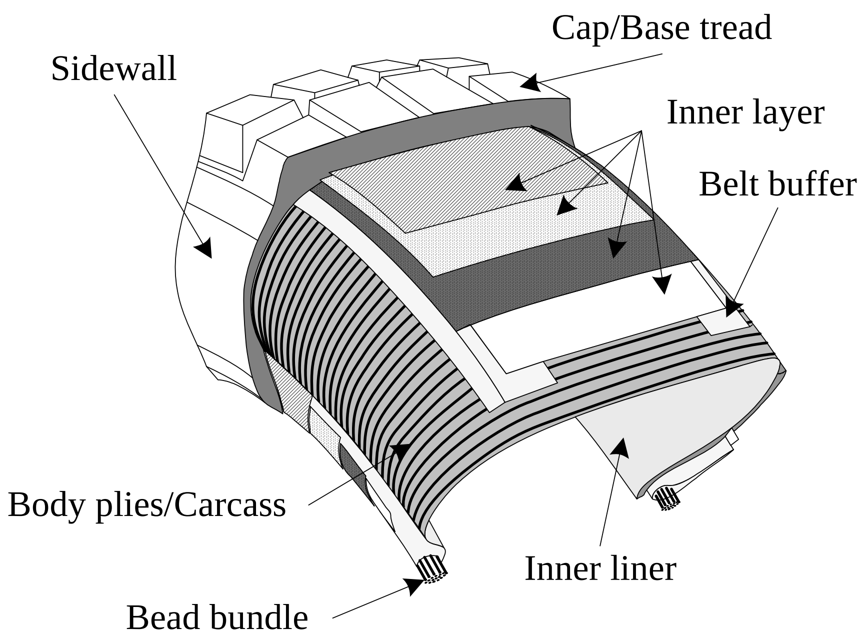

FIGURE 1.7. Illustration of a sample radial tire interior components and arrangement.

the road surface.

In a properly-inflated tire, approximately 95% *of the vehicle weight is supported by the air pressure in the tire and* 5% *is supported by the tire wall.*

1.2 Tire Components

A tire is an advanced engineering product made of rubber and a series of synthetic materials cooked together. Fiber, textile, and steel cords are some of the components that go into the tire's inner liner, body plies, bead bundle, belts, sidewalls, and tread. Figure 1.7 illustrates a sample of tire interior components and their arrangement.

The main components of a tire are explained below.

Bead or *bead bundle* is a loop of high strength steel cable coated with rubber. It gives the tire the strength it needs to stay seated on the wheel rim and to transfer the tire forces to the rim.

Inner layers are made up of different fabrics, called plies. The most common ply fabric is polyester cord. The top layers are also called cap plies. *Cap plies* are polyesteric fabric that help hold everything in place. Cap plies are not found on all tires; they are mostly used on tires with higher speed ratings to help all the components stay in place at high speeds.

An *inner liner* is a specially compounded rubber that forms the inside of a tubeless tire. It inhibits loss of air pressure.

Belts or belt buffers are one or more rubber-coated layers of steel, polyester, nylon, Kevlar or other materials running circumferentially around the tire under the tread. They are designed to reinforce body plies to hold the tread flat on the road and make the best contact with the road. Belts reduce squirm to improve tread wear and resist damage from impacts and penetration.

The *carcass* or *body plies* are the main part in supporting the tension forces generated by tire air pressure. The carcass is made of rubber-coated steel or other high strength cords tied to bead bundles. The cords in a radial tire, as shown in Figure 1.7, run perpendicular to the tread. The plies are coated with rubber to help them bond with the other components and to seal in the air.

A tire's strength is often described by the number of carcass plies. Most car tires have two carcass plies. By comparison, large commercial jetliners often have tires with 30 or more carcass plies.

The *sidewall* provides lateral stability for the tire, protects the body plies, and helps to keep the air from escaping from the tire. It may contain additional components to help increase the lateral stability.

The *tread* is the portion of the tire that comes in contact with the road. Tread designs vary widely depending on the specific purpose of the tire. The tread is made from a mixture of different kinds of natural and synthetic rubbers. The outer perimeter of a tire is also called the *crown.*

The *tread groove* is the space or area between two tread rows or blocks. The tread groove gives the tire traction and is especially useful during rain or snow.

Example 19 *Tire rubber main material.*

There are two major ingredients in a rubber compound: the rubber and the filler. They are combined in such a way to achieve different objectives. The objective may be performance optimization, traction maximization, or better rolling resistance. The most common fillers are different types of carbon black and silica. The other tire ingredients are antioxidants, antiozonant, and anti-aging agents.

Tires are combined with several components and cooked with a heat treatment. The components must be formed, combined, assembled, and cured together. Tire quality depends on the ability to blend all of the separate components into a cohesive product that satisfies the driver's needs. A modern tire is a mixture of steel, fabric, and rubber. Generally speaking, the weight percentage of the components of a tire are:

1− *Reinforcements: steel, rayon, nylon,* 16%
2− *Rubber: natural/synthetic,* 38%
3− *Compounds: carbon, silica, chalk,* 30%
4− *Softener: oil, resin,* 10%
5− *Vulcanization: sulfur, zinc oxide,* 4%
6− *Miscellaneous,* 2%

Example 20 *Tire cords.*

Because tires have to carry heavy loads, steel and fabric cords are used in their construction to reinforce the rubber compound and provide strength. The most common materials suitable for the tire application are cotton, rayon, polyester, steel, fiberglass, and aramid.

Example 21 *Bead components and preparation.*

The bead component of tires is a non-extensible composite loop that anchors the carcass and locks the tire into the rim. The tire bead components include the steel wire loop and apex or bead filler. The bead wire loop is made from a steel wire covered by rubber and wound around the tire with several continuous loops. The bead filler is made from a very hard rubber compound, which is extruded to form a wedge.

Example 22 *Tire ply construction.*

The number of plies and cords indicates the number of layers of rubber-coated fabric or steel cords in the tire. In general, the greater the number of plies, the more weight a tire can support. Tire manufacturers also indicate the number and type of cords used in the tire.

Example 23 ★ *Tire tread extrusion.*

Tire tread, or the portion of the tire that comes in contact with the road, consists of the tread, tread shoulder, and tread base. Since there are at least three different rubber compounds used in forming the tread profile, three rubber compounds are extruded simultaneously into a shared extruder head.

Example 24 ★ *Different rubber types used in tires.*

There are five major rubbers used in tire production: natural rubber, styrene-butadiene rubber (SBR), polybutadiene rubber (BR), butyl rubber, and halogenated butyl rubber. The first three are primarily used for tread and sidewall compounds, while butyl rubber and halogenated butyl rubber are primarily used for the inner liner and the inside portion that holds the compressed air inside the tire.

Example 25 ★ *History of rubber.*

About 2500 *years ago, people living in Central and South America used the sap and latex of a local tree to waterproof their shoes, and clothes. This material was introduced to the first pilgrim travelers in the* 17*th century. The first application of this new material was discovered by the English as an eraser. This application supports the name* ***rubber****, because it was used for rubbing out pencil marks. The rubber pneumatic tires were invented in* 1845 *and its production began in* 1888.

The natural rubber is a mixture of polymers and isomers. The main rubber isomer is shown in Figure 1.8 and is called ***isoprene****. The natural rubber may be vulcanized to make longer and stronger polyisopren, suitable for tire production. Vulcanization is usually done by sulfur as cross-links. Figure 1.9 illustrates a vulcanized rubber polymer.*

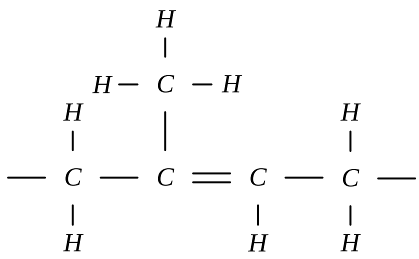

FIGURE 1.8. Illustration of the monomer unit of natural rubber.

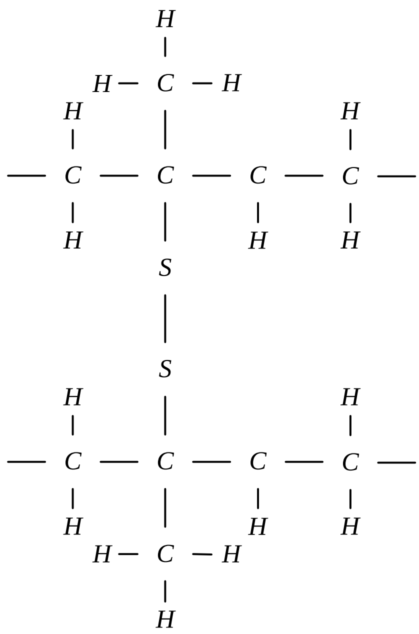

FIGURE 1.9. Illustration of a vulcanized rubber.

Example 26 ★ *A world without rubber.*

Rubber is the main material used to make a tire compliant. A compliant tire can stick to the road surface while it goes out of shape and provides distortion to move in another direction. The elastic characteristic of a tire allows the tire to be pointed in a direction different than the direction the car is pointed. There is no way for a vehicle to turn without rubber tires, unless it moves at a very low speed. If vehicles were equipped with only noncompliant wheels then trains moving on railroads would be the main travelling vehicles. People could not live too far from the railways and there would not be much use for bicycles and motorcycles.

1.3 Radial and Non-Radial Tires

Tires are divided in two classes: *radial* and *non-radial*, depending on the angle between carcass metallic cords and the tire-plane. Each type of tire

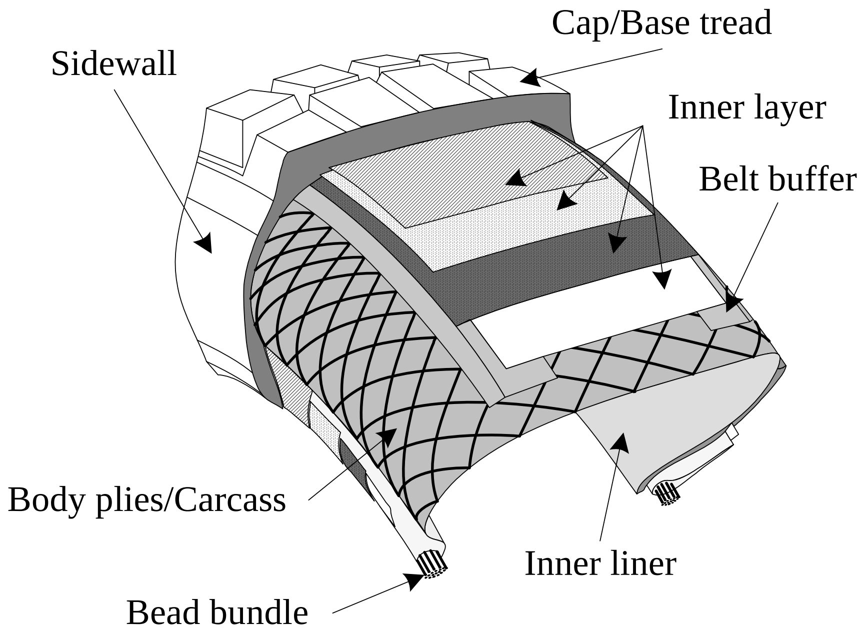

FIGURE 1.10. Examples of a non-radial tire's interior components and arrangement.

construction has its own set of characteristics that are the key to its performance.

The radial tire is constructed with reinforcing steel cable belts that are assembled in parallel and run side to side, from one bead to another bead at an angle of 90 deg to the circumferential centerline of the tire. This makes the tire more flexible radially, which reduces rolling resistance and improves cornering capability. Figure 1.7 shows the interior structure and the carcass arrangement of a radial tire.

The non-radial tires are also called *bias-ply* and *cross-ply* tires. The plies are layered diagonal from one bead to the other bead at about a 30 deg angle, although any other angles may also be applied. One ply is set on a bias in one direction as succeeding plies are set alternately in opposing directions as they cross each other. The ends of the plies are wrapped around the bead wires, anchoring them to the rim of the wheel. Figure 1.10 shows the interior structure and the carcass arrangement of a non-radial tire.

The most important difference in the dynamics of radial and non-radial tires is their different ground sticking behavior when a lateral force is applied on the wheel. This behavior is shown in Figure 1.11. The radial tire, shown in Figure 1.11(a), flexes mostly in the sidewall and keeps the tread flat on the road. The bias-ply tire, shown in Figure 1.11(b) has less contact with the road as both tread and sidewalls distort under a lateral load.

The radial arrangement of carcass in a radial tire allows the tread and sidewall act independently. The sidewall flexes more easily under the weight

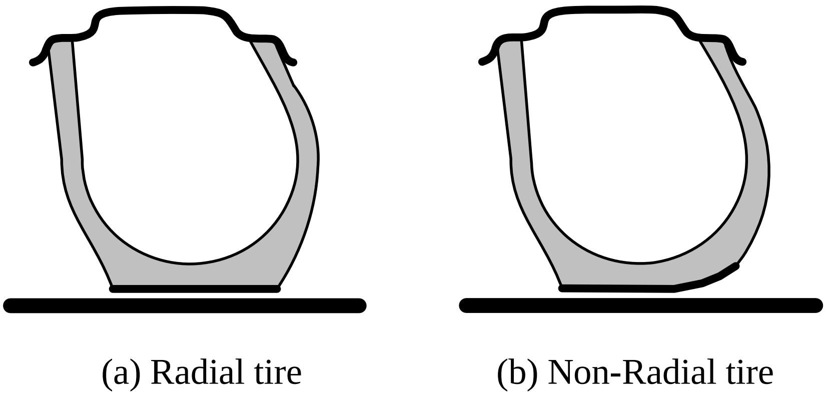

FIGURE 1.11. Ground-sticking behavior of radial and non-radial tires in the presence of a lateral force.

of the vehicle. So, more vertical deflection is achieved with radial tires. As the sidewall flexes under the load, the belts hold the tread firmly and evenly on the ground and reduces tread scrub. In a cornering maneuver, the independent action of the tread and sidewalls keeps the tread flat on the road. This allows the tire to hold its path. Radial tires are the preferred tire in most applications today.

The cross arrangement of carcass in bias-ply tires allows it act as a unit. When the sidewalls deflect or bend under load, the tread squeezes in and distorts. This distortion affects the tireprint and decrease traction. Because of the bias-ply inherent construction, sidewall strength is less than that of a radial tire's construction and cornering is less effective.

Example 27 *Increasing the strength of tires.*

The strength of bias-ply tires increases by increasing the number of plies and bead wires. However, more plies means more mass, which increases heat and reduces tire life. To increase a radial tire's strength, larger diameter steel cables are used in the tire's carcass.

Example 28 *Tubeless and tube-type tire construction.*

A tubeless tire is similar in construction to a tube-type tire, except that a thin layer of air and moisture-resistant rubber is used on the inside of the tubeless tire from bead to bead to obtain an internal seal of the casing. This eliminates the need for a tube and flap. Both tires, in equivalent sizes, can carry the same load at the same inflation pressure.

Example 29 ★ *New shallow tires.*

Low aspect ratio tires are radial tubeless tires that have a section width wider than their section height. The aspect ratio of these tires is between 50% *to* 30%. *Therefore, shallow tires have shorter sidewall heights and wider tread widths. This feature improves stability and handling from a higher lateral spring rates.*

Example 30 ★ *Tire function.*

A tire is a pneumatic system to support a vehicle's load. Tires support a vehicle's load by using compressed air to create tension in the carcass plies. Tire carcass are a series of cords that have a high tension strength, and almost no compression strength. So, it is the air pressure that creates tension in the carcass and carries the load. In an inflated and unloaded tire, the cords pull equally on the bead wire all around the tire. When the tire is loaded, the tension in the cords between the rim and the ground is relieved while the tension in other cords is unchanged. Therefore, the cords opposite the ground pull the bead upwards. This is how pressure is transmitted from the ground to the rim.

Besides vertical load carrying, a tire must transmit acceleration, braking, and cornering forces to the road. These forces are transmitted to the rim in a similar manner. Acceleration and braking forces also depend on the friction between the rim and the bead. A tire also acts as a spring between the rim and the road.

1.4 Tread

The tread pattern is made up of tread *lugs* and tread *voids*. The lugs are the sections of rubber that make contact with the road and voids are the spaces that are located between the lugs. Lugs are also called *slots* or *blocks*, and voids are also called *grooves*. The tire tread pattern of block-groove configurations affect the tire's traction and noise level. Wide and straight grooves running circumferentially have a lower noise level and high lateral friction. More lateral grooves running from side to side increase traction and noise levels. A sample of a tire tread is shown in Figure 1.12.

Tires need both circumferential and lateral grooves. The water on the road is compressed into the grooves by the vehicle's weight and is evacuated from the tireprint region, providing better traction at the tireprint contact. Without such grooves, the water would not be able to escape out to the sides of the wheel. This would causes a thin layer of water to remain between the road and the tire, which causes a loss of friction with the road surface. Therefore, the grooves in the tread provide an escape path for water.

On a dry road, the tire treads reduce grip because they reduce the contact area between the rubber and the road. This is the reason for using treadless or slick tires at smooth and dry race tracks.

The mud-terrain tire pattern is characterized by large lugs and large voids. The large lugs provide large bites in poor traction conditions and the large voids allow the tire to clean itself by releasing and expelling the mud and dirt. The all-terrain tire pattern is characterized by smaller voids and lugs when compared to the mud terrain tire. A denser pattern of lugs and smaller voids make all-terrain tires quieter on the street. However,

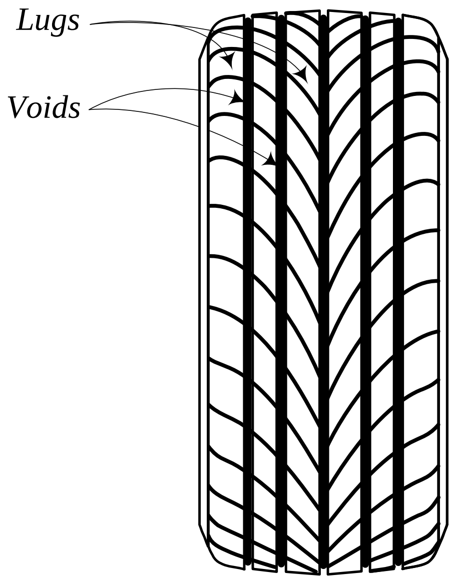

FIGURE 1.12. A sample of tire tread to show lugs and voids.

smaller voids cannot clean themselves easily and if the voids fill up with mud, the tire loses some of it's traction. The all-terrain tire is good for highway driving.

Example 31 *Asymmetrical and directional tread design.*

The design of the tread pattern may be asymmetric and change from one side to the other. Asymmetric patterns are designed to have two or more different functions and provide a better overall performance.

A directional tire is designed to rotate in only one direction for maximum performance. Directional tread pattern is especially designed for driving on wet, snowy, or muddy roads. A non-directional tread pattern is designed to rotate in either direction without sacrificing in performance.

Example 32 *Self-cleaning.*

Self-cleaning is the ability of a tire's tread pattern to release mud or material from the voids of tread. This ability provides good bite on every rotation of the tire. A better mud tire releases the mud or material easily from the tread voids.

1.5 ★ Hydroplaning

Hydroplaning is sliding of a tire on a film of water. Hydroplaning can occur when a car drives through standing water and the water cannot totally escape out from under the tire. This causes the tire to lift off the ground and slide on the water. The hydroplaning tire will have little traction and therefore, the car will not obey the driver's command.

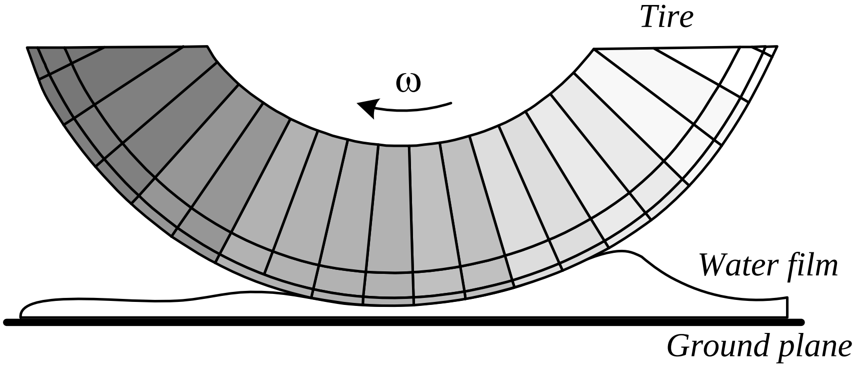

FIGURE 1.13. Illustration of hydroplaning phnomena.

Deep grooves running from the center front edge of the tireprint to the corners of the back edges, along with a wide central channel help water to escape from under the tire. Figure 1.13 illustrates the hydroplaning phenomena when the tire is riding over a water layer.

There are three types of hydroplaning: dynamic, viscous, and rubber hydroplaning. *Dynamic hydroplaning* occurs when standing water on a wet road is not displaced from under the tires fast enough to allow the tire to make pavement contact over the total tireprint. The tire rides on a wedge of water and loses its contact with the road. The speed at which hydroplaning happens is called *hydroplaning speed*.

Viscous hydroplaning occurs when the wet road is covered with a layer of oil, grease, or dust. Viscous hydroplaning happens with less water depth and at a lower speed than dynamic hydroplaning.

Rubber hydroplaning is generated by superheated steam at high pressure in the tireprint, which is caused by the friction-generated heat in a hard braking.

Example 33 *Aeronautic hydroplaning speed.*

In aerospace engineering the hydroplaning speed is estimated in [knots] by

$$v_H = 9\sqrt{p} \tag{1.6}$$

where, p is tire inflation pressure in [psi].

For main wheels of a B757 aircraft, the hydroplaning speed would be

$$\begin{aligned} v_H &= 9\sqrt{144} \\ &= 108\, knots \approx 55.5\,\mathrm{m/s}. \end{aligned}$$

Equation (1.6) for a metric system would be

$$v_x = 5.5753 \times 10^{-2}\sqrt{p} \tag{1.7}$$

where v_x is in $[\mathrm{m/s}]$ *and p is in* $[\mathrm{Pa}]$. *As an example, the hydroplaning*

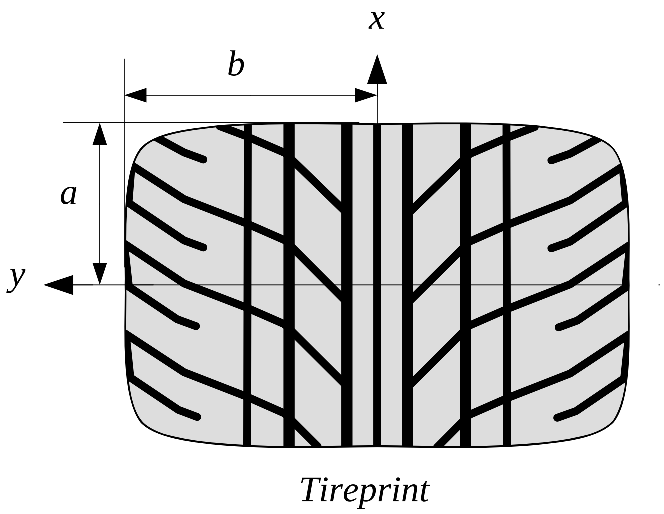

FIGURE 1.14. A tireprint.

speed of a car using tires with pressure $28psi \approx 193053\,\mathrm{Pa}$ *is*

$$\begin{aligned} v_x &= 5.5753 \times 10^{-2}\sqrt{193053} \\ &\approx 24.5\,\mathrm{m/\,s} \\ &\approx 47.6knots \approx 88.2\,\mathrm{km/\,h} \approx 54.8\,\mathrm{mi/\,h}. \end{aligned} \tag{1.8}$$

1.6 Tireprint

The contact area between a tire and the road is called the *tireprint* and is shown by A_P. At any point of a tireprint, the normal and friction forces are transmitted between the road and tire. The effect of the contact forces can be described by a resulting force system including force and torque vectors applied at the center of the tireprint.

The tireprint is also called *contact patch*, *contact region*, or *tire footprint.* A simplified model of tireprint is shown in Figure 1.14.

The area of the tireprint is inversely proportional to the tire pressure. Lowering the tire pressure is a technique used for off-road vehicles in sandy, muddy, or snowy areas, and for drag racing. Decreasing the tire pressure causes the tire to slump so more of the tire is in contact with the surface, giving better traction in low friction conditions. It also helps the tire grip small obstacles as the tire conforms more to the shape of the obstacle, and makes contact with the object in more places. Low tire pressure increases fuel consumption, tire wear, and tire temperature.

Example 34 *Uneven wear in front and rear tires.*

In most vehicles, the front and rear tires will wear at different rates. So, it is advised to swap the front and rear tires as they wear down to even out the wear patterns. This is called rotating the tires.

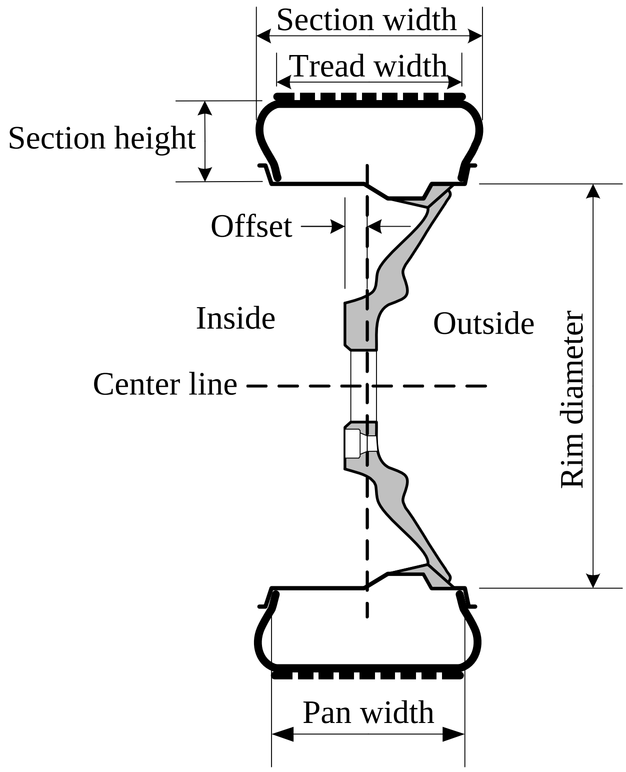

FIGURE 1.15. Illustration of a wheel and its dimensions.

Front tires, especially on front-wheel drive vehicles, wear out more quickly than rear tires.

1.7 Wheel and Rim

When a tire is installed on a rim and is inflated, it is called a wheel. A *wheel* is a combined tire and *rim*. The rim is the metallic cylindrical part where the tire is installed. Most passenger cars are equipped with steel rims. The steel rim is made by welding a disk to a shell. However, light alloy rims made with light metals such as aluminium and magnesium are also popular. Figure 1.15 illustrates a wheel and the most important dimensional names.

A rim has two main parts: *flange* and *spider*. The flange or *hub* is the ring or shell on which the tire is mounted. The spider or *center section* is the disc section that is attached to the hub. The rim width is also called pan width and measured from inside to inside of the bead seats of the flange. Flange provides lateral support to the tire. A flange has two *bead seats* providing radial support to the tire. The *well* is the middle part between the bead seats with sufficient depth and width to enable the tire beads to be mounted and demounted on the rim. The *rim hole* or *valve aperture* is the hole or slot in the rim that accommodates the valve for tire inflation.

There are two main rim shapes: 1− drop center rim (DC) and, 2− wide

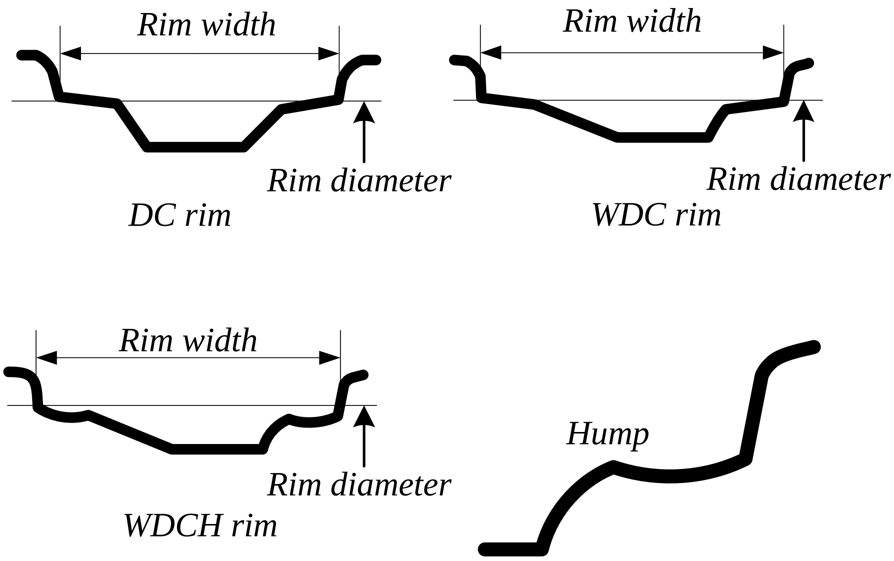

FIGURE 1.16. Illustration of DC, WDC, and WDCH rims and their geometry.

7 ½ – JJ × 15 55 5 – 114.3

7 1/2	Rim width [in]
JJ	Flange shape code
15	Rim diameter [in]
55	Offset [mm]
5	Number of bolts
114.3	Pitch circle diameter

FIGURE 1.17. A sample rim number.

drop center rim (WDC). The WDC may also come with a *hump*. The humped WDC may be called $WDCH$. Their cross sections are illustrated in Figure 1.16.

Drop center (DC) rims usually are symmetric with a well between the bead seats. The well is built to make mounting and demounting the tire easy. The bead seats are around 5 deg tapered. Wide drop center rims (WDC) are wider than DC rims and are built for low aspect ratio tires. The well of WDC rims are shallower and wider. Today, most passenger cars are equipped with WDC rims. The WDC rims may be manufactured with a hump behind the bead seat area to prevent the bead from slipping down.

A sample of rim numbering and its meaning is shown in Figure 1.17. Rim width, rim diameter, and offset are shown in Figure 1.15. Offset is

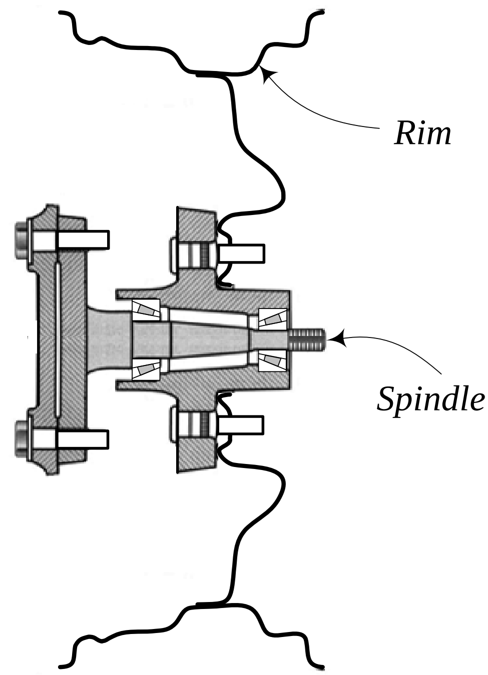

FIGURE 1.18. Illustration of a wheel attched to the spindle axle.

the distance between the inner plane and the center plane of the rim. A rim may be designed with a negative, zero, or positive offset. A rim has a positive offset if the spider is outward from the center plane.

The flange shape code signifies the tire-side profile of the rim and can be B, C, D, E, F, G, J, JJ, JK, and K. Usually the profile code follows the nominal rim width but different arrangements are also used. Figure 1.18 illustrates how a wheel is attached to the spindle axle.

Example 35 *Wire spoke wheel.*

A rim that uses wires to connect the center part to the exterior flange is called a wire spoke wheel, or simply a wire wheel. The wires are called spokes. This type of wheel is usually used on classic vehicles. The high-power cars do not use wire wheels because of safety. Figure 1.19 depicts two examples of wire spoke wheels.

Example 36 *Light alloy rim material.*

Metal is the main material for manufacturing, rims, however, new composite materials are also used for rims occasionally. Composite material rims are usually thermoplastic resin with glass fiber reinforcement, developed mainly for low weight. Their strength and heat resistance still need improvement before being a proper substitute for metallic rims.

Other than steel and composite materials, light alloys such as aluminum, magnesium, and titanium are used for manufacturing rims.

Aluminum is very good for its weight, thermal conductivity, corrosion resistance, easy casting, low temperature, easy machine processing, and recy-

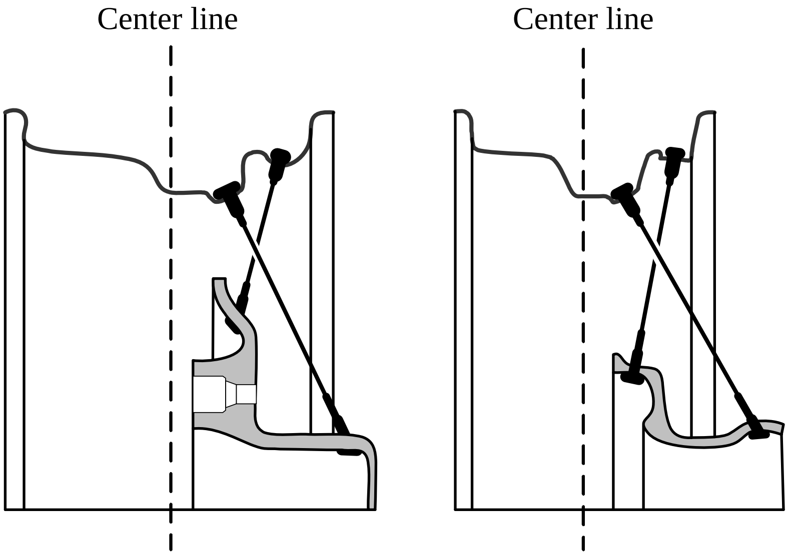

FIGURE 1.19. Two samples of wire spoke wheel.

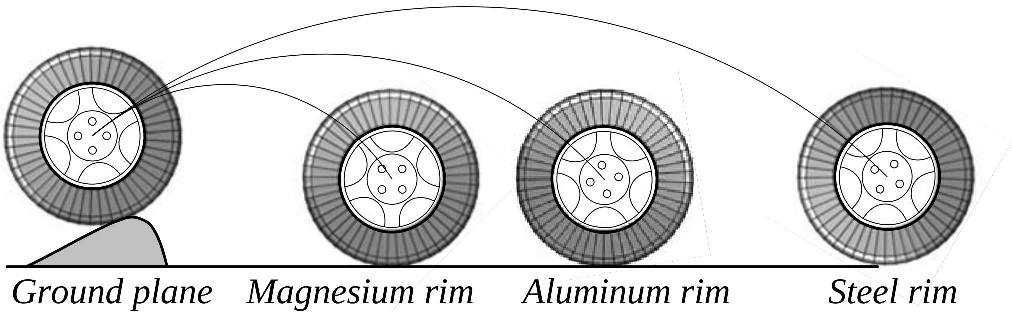

FIGURE 1.20. The difference between aluminum, magnesium, and steel rims in regaining road contact after a jump.

cling. Magnesium is about 30% *lighter than aluminum, and is excellent for size stability and impact resistance. However, magnesium is more expensive and it is used mainly for luxury or racing cars. The corrosion resistance of magnesium is not as good as aluminum. Titanium is much stronger than aluminum with excellent corrosion resistance. However, titanium is expensive and hard to be machine processed.*

The difference between aluminum, magnesium, and steel rims is illustrated in Figure 1.20. Light weight wheels regain contact with the ground quicker than heavier wheels.

Example 37 *Spare tire.*

Road vehicles typically carry a spare tire, which is already mounted on a rim ready to use in the event of flat tire. After 1980*, some cars have been equipped with spare tires that are smaller than normal size. These spare tires are called doughnuts or space-saver spare tires. Although the doughnut spare tire is not very useful or popular, it can help to save a little space,* *weight, cost, and gas mileage. Doughnut spare tires can not be driven far or fast.*

Example 38 *Wheel history.*

Stone and wooden wheels were invented and used somewhere in the Middle East about 5000 *years ago. Hard wheels have some inefficient characteristics namely poor traction, low friction, harsh ride, and poor load carrying capacity.*

Solid rubber tires and air tube tires began to be used in the late nineteen and early twentieth century.

1.8 Vehicle Classifications

Road vehicles are usually classified based on their size and number of axles. Although there is no standard or universally accepted classification method, there are a few important and applied vehicle classifications.

1.8.1 ISO and FHWA Classification

ISO3833 classifies ground vehicles in 7 groups:

1− Motorcycles
2− Passenger cars
3− Busses
4− Trucks
5− Agricultural tractors
6− Passenger cars with trailer
7− Truck trailer/semi trailer road trains

The Federal Highway Administration (FHWA) classifies road vehicles based on size and application. All road vehicles are classified in 13 classes as described below:

1− Motorcycles
2− Passenger cars, including cars with a one-axle or two-axle trailer
3− Other two-axle vehicles, including: pickups, and vans, with a one-axle or two-axle trailer
4− Buses
5− Two axle, six-tire single units
6− Three-axle single units
7− Four or more axle single units
8− Four or fewer axle single trailers
9− Five-axle single trailers
10− Six or more axle single trailers
11− Five or less axle multi-trailers

12– Six-axle multi-trailers
13– Seven or more axle multi-trailers

Figure 1.21 illustrates the FHWA classification. The definition of FHWA classes follow.

Motorcycles: Any motorvehicle having a seat or saddle and no more than three wheels that touch the ground is a motorcycle. Motorcycles, motor scooters, mopeds, motor-powered or motor-assisted bicycles, and three-wheel motorcycles are in this class. Motorcycles are usually, but not necessarily, steered by handlebars. Figure 1.22 depicts a three-wheel motorcycle.

Passenger Cars: Street cars, including sedans, coupes, and station wagons manufactured primarily for carrying passengers, are in this class. Figure 1.23 illustrates a two-door passenger car. Passenger cars are also called street cars, *automobiles*, or *autos.*

Other Two-Axle, Four-Tire Single-Unit Vehicles: All two-axle, four-tire vehicles other than passenger cars make up this class. This class includes pickups, panels, vans, campers, motor homes, ambulances, hearses, carryalls, and minibuses. Other two-axle, four-tire single-unit vehicles pulling recreational or light trailers are also included in this class. Distinguishing class 3 from class 2 is not clear, so these two classes may sometimes be combined into class 2.

Buses: A motor vehicle able to carry more than ten persons is a bus. Buses are manufactured as traditional passenger-carrying vehicles with two axles and six tires. However, buses with three or more axles are also manufactured.

Two-Axle, Six-Tire, Single-Unit Trucks: Vehicles on a single frame including trucks, camping and recreational vehicles, motor homes with two axles, and dual rear wheels are in this class.

Three-Axle Single-Unit Trucks: Vehicles having a single frame including trucks, camping, recreational vehicles, and motor homes with three axles are in this class.

Four-or-More-Axle-Single-Unit Trucks: All trucks on a single frame with four or more axles make up this class.

Four-or-Fewer-Axle Single-Trailer Trucks: Vehicles with four or fewer axles consisting of two units, one of which is a tractor or straight truck power unit, are in this class.

Five-Axle Single-Trailer Trucks: Five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit, are in this class.

Six-or-More-Axle Single-Trailer Trucks: Vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit, are in this class.

Five-or-Fewer-Axle Multi-Trailer Trucks: Vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit, are in this class.

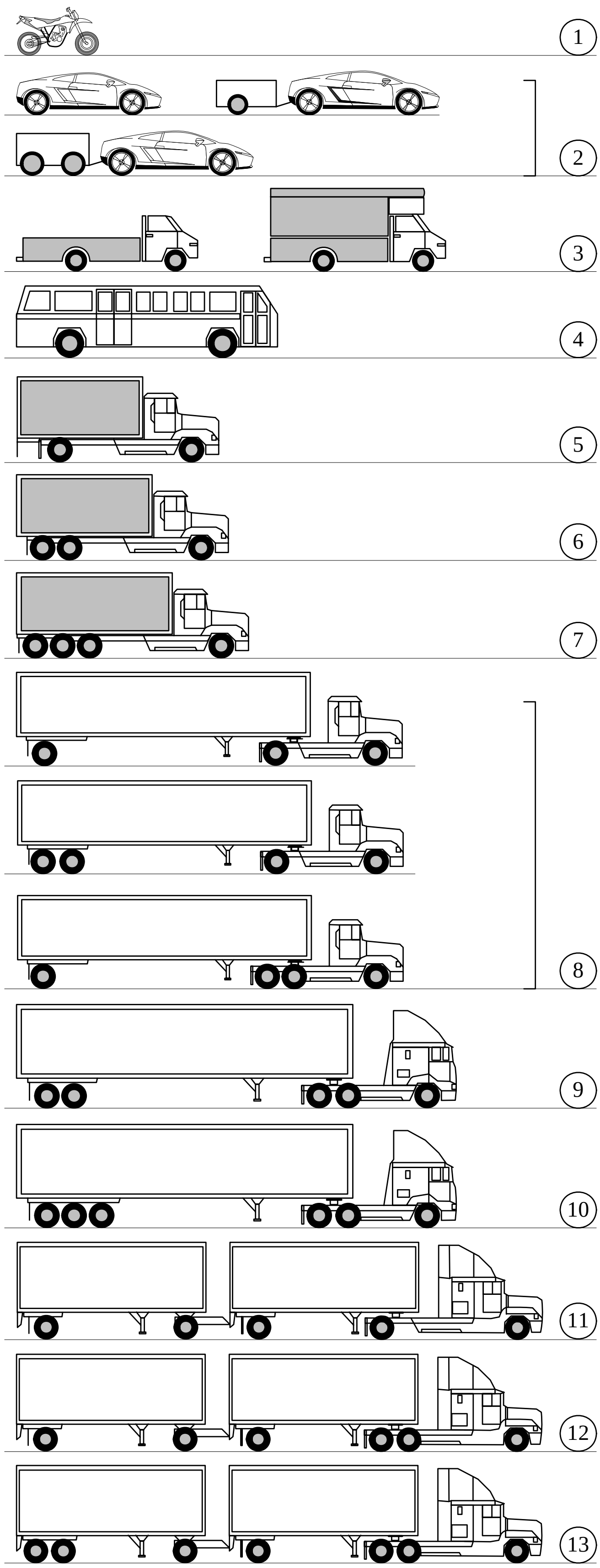

FIGURE 1.21. The FHWA vehicle classification.

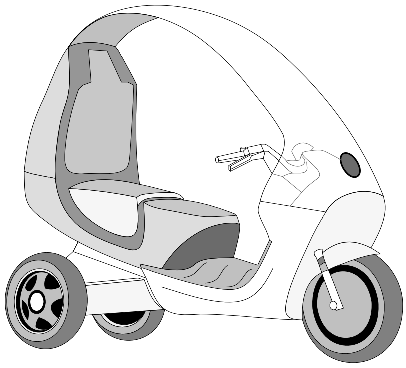

FIGURE 1.22. A three-wheel motorcycle.

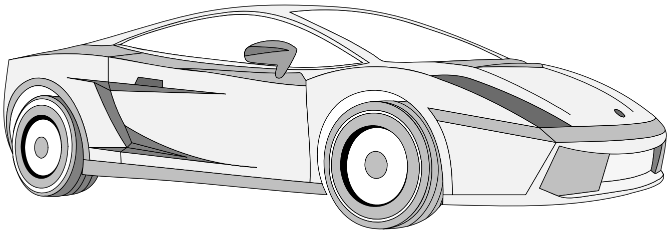

FIGURE 1.23. A two-door passenger car.

Six-Axle Multi-Trailer Trucks: Six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit, are in this class.

Seven or More Axle Multi-Trailer Trucks: Vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit are in this class.

The classes 6 to 13 are also called truck. A *truck* is a motor vehicle designed primarily for carrying load and/or property.

1.8.2 Passenger Car Classifications

A passenger car or automobile is a motorvehicle designed for carrying ten or fewer persons. Automobiles may be classified based on their size and weight. Size classification is based on wheelbase, the distance between front and rear axles. Weight classification is based on curb weight, the weight of an automobile with standard equipment, and a full complement of fuel and other fluids, but with no load, persons, or property. The wheelbase is rounded to the nearest inch and the curb weight to the nearest $100\,\mathrm{lb} \approx 50\,\mathrm{kg}$ before classification.

For a size classification, passenger car may be classified as a *small*, *midsize*, and *large* car. *Small cars* have a wheelbase of less than $99\,\mathrm{in} \approx 2.5\,\mathrm{m}$, *midsize cars* have a wheelbase of less than $109\,\mathrm{in} \approx 2.8\,\mathrm{m}$ and greater than $100\,\mathrm{in} \approx 2.5\,\mathrm{m}$, and *large cars* have a wheelbase of more than $110\,\mathrm{in} \approx 2.8\,\mathrm{m}$.

Each class may also be divided further.

For a weight classification, passenger car may be classified as *light*, *midweight*, and *heavy*. *Light weight cars* have a curb weight of less than 2400 lb $\approx$ 1100 kg, *midweight cars* have a curb weight of less than 3400 lb $\approx$ 1550 kg and more than 2500 lb $\approx$ 1150 kg, and *heavy cars* have a curb weight of more than 3500 lb $\approx$ 1600 kg. Each class may also be divided in some subdivisions.

Dynamically, passenger cars may be classified by their type of suspension, engine, driveline arrangement, weight distribution, or any other parameters that affect the dynamics of a car. However, in the market, passenger cars are usually divided into the following classes according to the number of passengers and load capacity.

1− Economy
2− Compact
3− Intermediate
4− Standard Size
5− Full Size
6− Premium Luxury
7− Convertible Premium
8− Convertible
9− Minivan
10− Midsize
11− SUV

In another classification, cars are divided according to size and shape. However, using size and shape to classify passenger cars is not clear-cut; many vehicles fall in between classes. Also, not all are sold in all countries, and sometimes their names differ between countries. Common entries in the shape classification are the *sedan*, *coupe*, *convertible*, *minivan/van*, *wagon*, and *SUV*.

A *sedan* is a car with a four-door body configuration and a conventional trunk or a sloping back with a hinged rear cargo hatch that opens upward.

A *coupe* is a two-door car.

A *convertible* is a car with a removable or retractable top.

A *minivan/van* is a vehicle with a box-shaped body enclosing a large cargo or passenger area. The identified gross weight of a van is less than 10 000 lb $\approx$ 4 500 kg. Vans can be identifiable by their enclosed cargo or passenger area, short hood, and box shape. Vans can be divided into *mini van*, *small van*, *midsize van*, *full-size van*, and *large van*. The van subdivision has the same specifications as SUV subdivisions.

A *wagon* is a car with an extended body and a roofline that extends past the rear doors.

An *SUV* (sport utility vehicle) is a vehicle with off-road capability. SUV is designed for carrying ten or fewer persons, and generally considered a multi-purpose vehicle. Most SUVs are four-wheel-drive with and increased ground clearance. The SUV is also known as 4-by-4, $4WD$, 4×4 or $4x4$. SUVs can be divided into *mini*, *small*, *midsize*, *full-size*, and *large SUV*.

Mini SUVs are those with a wheelbase of less than or equal to 88 in $\approx$ 224 cm. A mini SUV is typically a microcar with a high clearance, and off-road capability. Small SUVs have a wheelbase of greater than 88 in $\approx$ 224 cm with an overall width of less than 66 in $\approx$ 168 cm. Small SUVs are short and narrow 4×4 multi-purpose vehicles. Midsize SUVs have a wheelbase of greater than 88 in $\approx$ 224 cm with an overall width greater than 66 in $\approx$ 168 cm, but less than 75 in $\approx$ 190 cm. Midsize SUVs are 4×4 multi-purpose vehicles designed around a shortened pickup truck chassis. Full-size SUVs are made with a wheelbase greater than 88 in $\approx$ 224 cm and a width between 75 in $\approx$ 190 cm and 80 in $\approx$ 203 cm. Full-size SUVs are 4×4 multi-purpose vehicles designed around an enlarged pickup truck chassis. Large SUVs are made with a wheelbase of greater than 88 in $\approx$ 224 cm and a width more than 80 in $\approx$ 203 cm.

Because of better performance, the vehicle manufacturing companies are going to make more cars four-wheel-drive. So, four-wheel-drive does not refer to a specific class of cars anymore.

A *truck* is a vehicle with two or four doors and an exposed cargo box. A light truck has a gross weight of less than 10 000 lb $\approx$ 4 500 kg. A medium truck has a gross weight from 10 000 lb $\approx$ 4 500 kg to 26 000 lb $\approx$ 12 000 kg. A heavy truck is a truck with a gross weight of more than 26 000 lb $\approx$ 12 000 kg.

1.8.3 Passenger Car Body Styles

Passenger cars are manufactured in so many different styles and shapes. Not all of those classes are made today, and some have new shapes and still carry the same old names. Some of them are as follows:

Convertible or *cabriolet* cars are automobiles with removable or retractable rooves. There are also the subdivisions *cabrio coach* or *semi-convertible* with partially retractable rooves.

Coupé or *coupe* are two-door automobiles with two or four seats and a fixed roof. In cases where the rear seats are smaller than regular size, it is called a two-plus-two or $2 + 2$. Coupé cars may also be convertible.

Crossover SUV or *XUV* cars are smaller sport utility vehicles based on a car platform rather than truck chassis. Crossover cars are a mix of SUV, minivan, and wagon to encompass some of the advantages of each.

Estate car or just *estate* is the British/English term for what North Americans call a station wagon.

Hardtop cars are those having a removable solid roof on a convertible car. However, today a fixed-roof car whose doors have no fixed window frame are also called a hardtops.

Hatchback cars are identified by a rear door, including the back window that opens to access a storage area that is not separated from the rest of the passenger compartment. A hatchback car may have two or four doors and two or four seats. They are also called three-door, or five-door cars. A hatchback car is called a *liftback* when the opening area is very sloped and is lifted up to open.

A *limousine* is a chauffeur-driven car with a glass-window dividing the front seats from the rear. Limousines are usually an extended version of a luxury car.

Minivans are boxy wagon cars usually containing three rows of seats, with a capacity of six or more passengers and extra luggage space.

An *MPV* (*multi-purpose vehicle*) is designed as large cars or small buses having off-road capability and easy loading of goods. However, the idea for a car with a multi-purpose application can be seen in other classes, especially SUVs.

Notchback cars are something between the hatchback and sedan. Notchback is a sedan with a separate trunk compartment.

A *pickup truck (*or simply *pickup*) is a small or medium-sized truck with a separate cabin and rear cargo area. Pickups are made to act as a personal truck, however they might also be used as light commercial vehicles.

Sedan is the most common body style that are cars with four or more seats and a fixed roof that is full-height up to the rear window. Sedans can have two or four doors.

Station wagon or wagon is a car with a full-height body all the way to the rear; the load-carrying space created is accessed via a rear door or doors.

1.9 Summary

Tires are the only component of a vehicle to transfer forces between the road and the vehicle. Tire classification parameters are indicated on the sidewall, such as dimensions, maximum load-carrying capacity, and maximum speed index. A sample of tire size and performance code is shown in Figure 1.24 and their definitions are explained as follows:

P 215 / 60 R 15 96 H

FIGURE 1.24. A sample of tire size.

$\boxed{P}$ stands for passenger car. $\boxed{215}$ is the unloaded tire width, in [mm]. $\boxed{60}$ is the aspect ratio of the tire, $s_T = \frac{h_T}{w_T} \times 100$, which is the section height to tire width, expressed as a percentage. $\boxed{R}$ stands for radial. $\boxed{15}$ is the rim diameter that the tire is designed to fit in [in]. $\boxed{96}$ is the load index, and $\boxed{H}$ is the speed rate index.

Road vehicles are usually classified based on their size and number of axles. There is no universally accepted standard classification, however, ISO and FHWA present two important classifications in North America. ISO3833 classifies ground vehicles into seven groups:

1- Motorcycles
2- Passenger cars
3- Busses
4- Trucks
5- Agricultural tractors
6- Passenger cars with trailer
7- Truck trailer/semitrailer road trains

FHWA classifies all road vehicles into 13 classes:Motorcycles

1- Motorcycles
2- Passenger cars with one or two axles trailer
3- Other two-axle four-wheel single units
4- Buses
5- Two-axle six-wheel single units
6- Three-axle single units
7- Four-or-more-axle single units
8-Four-or-less-axle single trailers
9-Five-axle single trailers
10-Six-or-more-axle single trailers
11-Five-or-less-axle multi-trailers
12-Six-axle-multi-trailers
13-Seven-or-more-axle multi-trailers

1.10 Key Symbols

A_P	tireprint area
B	bias ply tire
D	tire diameter
D	diagonal
DC	drop center rim
DOT	Department of Transportation
$FHWA$	Federal Highway Administration
h_T	section height
H	speed rate
$WDCH$	humped wide drop center rim
LT	light truck
$M\&S$	mud and snow
p	tire inflation pressure
P	passenger car
R	radial tire
s_T	aspect ratio
ST	special trailer
T	temporary tire
v_H	hydroplaning speed
v, v_x	forward velocity of vehicle
w_T	tire width
WDC	wide drop center rim

Exercises

1. Problem of tire beads.

   Explain what would be the possible problem for a tire that has tight or loose beads.

2. Tire size codes.

   Explain the meaning of the following tire size codes:

   (a)
   $$10.00R20\ 14(G)$$

   (b)
   $$18.4R46$$

   (c)
   $$480/80R46155A8$$

   (d)
   $$18.4-38(10)$$

   (e)
   $$76\times 50.00B32=1250/45B32$$

   (f)
   $$LT255/85B16$$

   (g)
   $$33x12.50R15LT$$

3. Tire height and diameter.

   Find the tire height h_T and diameter D for the following tires.

   (a)
   $$480/80R46\ 155A8$$

   (b)
   $$P215/65R15\ 96H$$

4. ★ Plus one.

   Increase 1 in to the diameter of the rim of the following tires and find a proper tire for the new rim.

   $$P215/65R15\ 96H$$
   $$P215/60R15\ 96H$$

5. Tire of Porsche 911 turbo^{TM}.

   A model of Porsche 911 turbo^{TM} uses the following tires.

$$\begin{array}{ll} front & 235/35ZR19 \\ rear & 305/30ZR19 \end{array}$$

   Determine and compare h_T, and D for the front and rear tires.

6. Tire of Porsche Cayenne turbo^{TM}.

   A model of Porsche Cayenne turbo^{TM} is an all-wheel-drive that uses the following tire.

$$255/55R18$$

   What is the angular velocity of its tires when it is moving at the top speed $v = 171\,\mathrm{mi/\,h} \approx 275\,\mathrm{km/\,h}$?

7. Tire of Ferrari P 4/5 by Pininfarina^{TM}.

   A model of Ferrari P 4/5 by Pininfarina^{TM} is a rear-wheel-drive sport car that uses the following tires.

$$\begin{array}{ll} front & 255/35ZR20 \\ rear & 335/30ZR20 \end{array}$$

   What is the angular velocity of its tires when it is moving at the top speed $v = 225\,\mathrm{mi/\,h} \approx 362\,\mathrm{km/\,h}$?

8. Tire of Mercedes-Benz SLR 722 Edition^{TM}.

   A model of Mercedes-Benz SLR 722 Edition^{TM} uses the following tires.

$$\begin{array}{ll} front & 255/35R19 \\ rear & 295/30R19 \end{array}$$

   What is the speed of this car if its rear tires are turning at

$$\omega = 2000\ rmp.$$

   At that speed, what would be the angular velocity of the front tires?

9. Tire of Chevrolet Corvette $Z06^{TM}$.

   A model of Chevrolet Corvette $Z06^{TM}$ uses the following tires.

$$\begin{array}{ll} front & 275/35ZR18 \\ rear & 325/30ZR19 \end{array}$$

   What is the speed of this car if its rear tires are turning at

$$\omega = 2000\ rmp.$$

   At that speed, what would be the angular velocity of the front tires?

10. Tire of Koenigsegg CCX^{TM}.

    Koenigsegg CCX^{TM} is a sport car, equipped with the following tires.

$$\begin{array}{ll} front & 255/35R19 \\ rear & 335/30R20 \end{array}$$

    What is the angular speed ratio of the rear tire to the front tire?