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Chapter 2
Dimensions, Materials, and Environmental Conditions

Project 1
Fatigue Analysis of Wheel Lug Stud/Wheel lug bolt

Vehicle:
Toyota RAV4 XLE 2015

Wheel Lug Stud

AME 3353
Design of Mechanical Components
Professor H. L. Stalford

2.1 Geometry and Dimension

The mechanical component being analysed is a lug stud of the front right wheel of a Toyota RAV4 XLE. These lug studs have to be standardised for safety issues. For example, the thread size or the pitch needs to meet a certain standard. This is also so that when consumers purchase, they can be more confident in the product they are buying. Many times, these studs are also manufactured in different units. For example, the one I have used is in metric, but it can change from stud to stud as it varies from companies to companies that manufacture them. The one I have bought is from Dorman[1] and can be seen in the figure 2.1-1.

Figure 2.1-1: Wheel lug stud

The tyre for RAV 4 XLE is marked as 225/ 65R17. This information can be found in the picture below (figure 2.1-2) from the front right tyre.

Figure 2.1-2: Description of the tyre type

From the code above, 225 is the width of the tyre in millimetres. This is 22.5 cm and 8.85". This conversion is given in equation 2.1-1. Decoding this code is mentioned in etrailer website[2].

$$22.5 cm * 2.54 \frac{in}{cm} = 8.85\ in \tag{2.1-1}$$

The second number 65 is the sidewall aspect ratio. This means that the section height is 65% of the tyre width.

$$8.85\ in * \frac{65}{100} = 5.75\ in \tag{2.1-2}$$

The section width is 5.75 in as found in equation 2.1-2. And the last number is rim diameter, which is 17 in. Therefore, the tyre radius is 8.5 in. The circumference is found by the formula (equation 2.1-3)

$$Circumference = 2 * \pi * r = 2 * \pi * 8.5\ in = 53.41\ in \qquad (2.1\text{-}3)$$

The dimensions have been summarised below:

225/65R17: Tyre Radius : 8.5", Diameter : 17", Circumference : 53.41", Tyre Width : 5.75"

Figure 2.1-3: Hub of the front right wheel where the lug stud goes

The diameter of the hub is measured to be 16.8 cm or 6.61 in. Therefore, the distance from the centre of the hub to the top is 8.4 cm or 3.31 in.
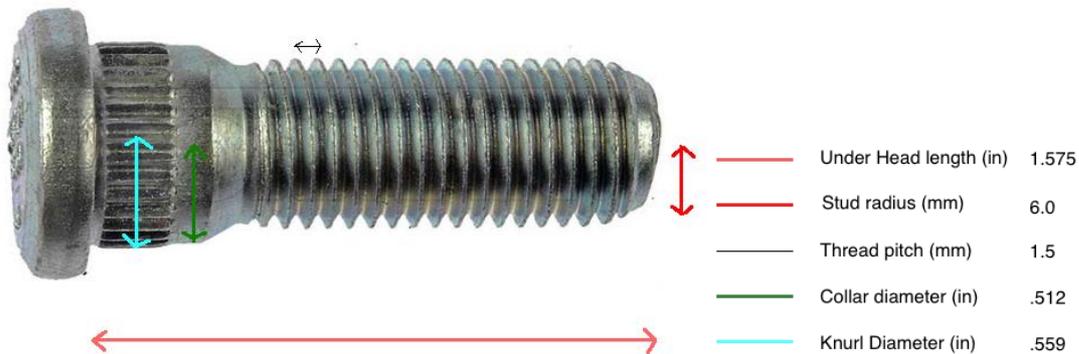

Under Head length (in)	1.575
Stud radius (mm)	6.0
Thread pitch (mm)	1.5
Collar diameter (in)	.512
Knurl Diameter (in)	.559

Figure 2.1-4: Lug stud with dimensions

The table with various other dimensions is given below (Table 2.1-1)[3].

Table 2.1-1: Table with lug stud dimensions

Geometry description	Dimension in inches	Dimension in centimetres
Stud diameter at the thread	.472	1.20
Stud radius	.236	0.60
Thread Pitch	.059	0.15
Mean thread diameter of thread contact	.484	1.23
Collar diameter	.512	1.30
Pitch circle diameter	.484	1.24
Shoulder length	.441	1.12
Thread size	1.134	2.88
Knurl diameter	.559	1.42
Under head length	1.575	4.00
Cross sectional area	.175 in^2	1.13 cm^2

The wheel lug stud at Dorman is manufactured using the metric units. In the table below, all the wheel, rim and tyre information can be found also the figure to allow for the understanding of the different dimensions.

Figure 2.1-5: Location of lug stud on the front right wheel

The geometry and dimensions of the wheel, tyre and the hub are shown in the figure below (figure 2.1-5). These were measured using a 12 inches ruler in daylight. There is a 5 lug stud pattern on the rim and this pattern can vary from car to car.
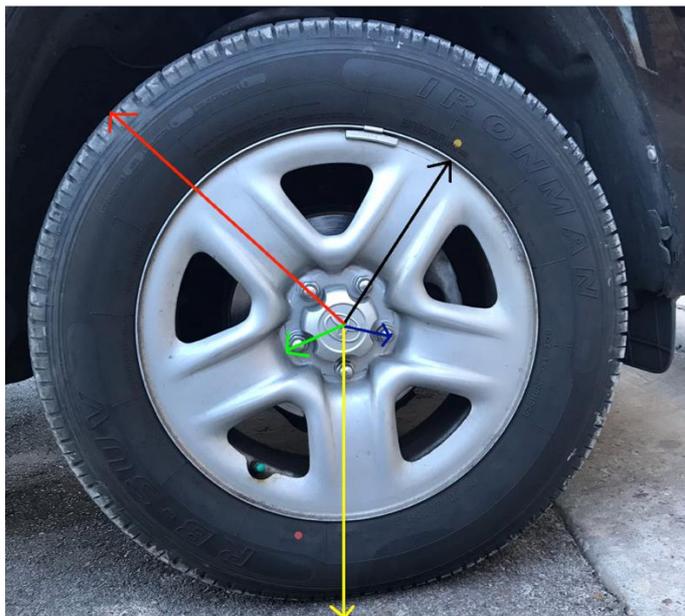
Wheel to ground		14.25 in
Radius - center to stud		2.36 in
Radius - rim		8.5 in
Radius - hub		3.15 in
Radius - tyre		14.25 in

Figure 2.1-6: Geometry and Dimensions of Wheel, tyre and rim

The figure 2.1-6 above displays the different dimensions of the tyre. This was again measured using a 12 in ruler.

2.2 Materials

The lug stud used in Toyota RAV 4 XLE 2015 is make 10.9 in (Society of Automatic Engineers) SAE grade. This was found at the back of the wheel lug stud. On Uboltit.com, the 10.9 grade stud is manufactured using AISI 1045 Medium Carbon Steel alloy that has been quenched and tempered[4], which has a composition of .29%-0.54% carbon, with 0.60%-1.65% Manganese and the rest as Iron. This particular steel type is very strong and ductile making it the choice for its long wearing properties[5].

It is noted that a wheel lug stud needs to be changed every 123,000 km, on average, where it either starts to rust or the threading starts to wear[6] out. The wheel lug stud failure rate is about 3% per year. Since the temperature in the hottest part of the world is about 50°C, the temperature of the tyre can go up to around 60°C[7]. This is why these lug studs are made from medium carbon steel, which is very durable in such extreme weather/climate. Similarly, since it is not dissolvable in water, it can withstand very high humidity near the equator also. Toyota cars are sold in extreme weathers like Libya and Niger, and also in Russia and Greenland. Similarly, Toyota cars are also sold in sea-side cities and also in extreme humidity[8]. There was no information available for potential galvanic cell conditions for the lug stud.

2.3 Material Properties

The material properties of the wheel lug stud have been mentioned in the table 2.3-1. Their individual calculations are mentioned below the table. The material selected for the lug stud is Medium Carbon steel as mentioned above.

Table 2.3-1: Material properties of wheel lug stud

Properties	Value in English Units	Value in Metric Units
Ultimate Tensile Strength (S_u)	151 ksi	1040 MPa
Ultimate Shear Strength (S_{us})	113 ksi	780 MPa
Tensile Yield Strength (S_y)	136 ksi	940 MPa
Shear Yield Strength (S_{sy})	87 ksi	547 MPa
Young's modulus (E)	30,168 ksi	208 GPa
Shear Modulus (G)	11,600 ksi	80 GPa
Poisson ratio	0.29	0.29

The ultimate tensile strength and tensile strength were gained from the Fundamentals of Machine Component Design textbook[9]. From the same textbook, values for Ultimate Shear Strength and Shear Yield Strength were calculated as the discreet values were not available online. The calculations are given below:

$$S_{us} = 0.75 * S_u = 0.75 * 1040\ MPa = 780\ MPa \qquad (2.3\text{-}1)$$
$$S_{sy} = 0.577 * S_y = 0.577 * 940\ MPa = 547\ MPa \qquad (2.3\text{-}2)$$

The value of Young's modulus was found at the MIT Library database[10]. The shear Modulus and Poisson Ratio at Azo Material[11].

2.4 Table of Data

All the data from the document has been placed in the table 2.4-1 below.

Table 2.4-1: Data of Geometry, Dimensions and Material Properties of Mechanical Component and Vehicle

Parameter	Description	Value in English Units	Value in Metric units
W curb	**vehicle curb weight**	3445 lbs	1562 kg
W-full	**vehicle full capacity weight**	4370 lbs	1982 kg
Length	**Length of the car**	179.9 in	4.57 m
Width	**Width of the car without the mirror**	72.6 in	1.84 m
Height	**Height of the car**	65.4 in	1.66 m
CG	**Location of center of gravity of the car**	Low cg	N/A
Stud thread	**Total threads in the stud**	20 beads	20 beads

Wheel D	Wheel diameter	17 in	43.18 cm
Hub R	Hub radius: distance from center of hub to top of hub	3.15 in	8.0 cm
Hub D	Hub diameter	6.30 in	16.0 cm
Rim Holes Conf. D	Diameter distance across rim configuration of stud/lug bolt holes	4.72 in	12.0 cm
Rim Holes Conf. R	Radius of rim configuration of stud/lug bolt holes	2.36 in	6.0 cm
Rground	Distance from ground to center of hub	14.25 in	16.2 cm
dm	Diameter thread size of lug nut/lug stud/lug bolt	0.472 in	1.2 cm
Am	Bolt cross-sectional area using dm=thread size	$0.175\ in^2$	$1.13\ cm^2$
dc	Collar 'washer' diameter or lug nut outer diameter	.512 in	1.30 cm
L(lead) or p (pitch)	Thread pitch p of lug nut/lug stud/lug bolt	.059	.15 cm
Sy	Tensile yield strength of lug nut/lug stud/lug bolt	136 ksi	940 MPa
Su	Ultimate tensile strength of lug nut/lug stud/lug bolt	151 ksi	1040 MPa
Sus	Ultimate shear strength of lug nut/lug stud/lug bolt	113 ksi	780 MPa
Ssy	Shear yield strength of lug nut/lug stud/lug bolt	87 ksi	547 MPa
E	Young's modulus of lug nut/lug stud/lug bolt	30,168 ksi	208 GPa
G	Shear modulus of lug nut/lug stud/lug bolt	11,600 ksi	80 GPa
v	Poisson's ratio of lug nut/lug stud/lug bolt	0.29	0.29

2.5 References

[1] "Hardware Store." *Dorman Products - Home Page*, www.dormanproducts.com/.

[2] *How to Determine Tire/Wheel Diameter*, www.etrailer.com/faq-determining-tire-wheel-diameter.aspx.

[3] "Wheel Lug Stud." *Oreilly Auto Parts Toyota RAV4 XLE 2015 - Wheel Lug Stud*, www.oreillyauto.com/detail/dorman-autograde-3358/tire---wheel-16779/wheel-lug-stud-12672/dorman-autograde-wheel-stud/610266/4181186/2015/toyota/rav4?fitAttr_10039=Front#show_applications.

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9 Juvinall, Robert C., and Kurt M. Marshek. "Threaded Fasteners and Power Screws." *Fundamentals of Machine Component Design*, John Wiley & Sons, Inc., 2017, pp. 433–434.

10 Slocum, Alexandor. "Material Data Book." *Mdp.eng.cam.ac.uk*, www-mdp.eng.cam.ac.uk/web/library/enginfo/cueddatabooks/materials.pdf.

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2.6 Level of Effort

I spent about 16 hours in this project. This was especially hard because I had to first find a car I could use for the project. I also took time out to visit AutoZone and have a look at the lug stud and get a feel for it. Since I don't have a car, I had to cycle there. When I did go there, they did not have the part so I had to go back 2 days later to get it again on my bike. Besides that, I think I am learning a lot about cars from this project and am excited for it.