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Effects of Change in Tire Pressure Upon Efficiency of a Vehicle

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Effects of Change in Tire Pressure Upon Efficiency of a Vehicle

Abstract

The objective of this paper is to compare the difference in the efficiency of acceleration, of a 2018 Audi A8, in two distinct scenarios where the tire pressure is kept at a maximum and partial level. The approach towards solving the issue is multi-faceted, the efficiency is dependent on the difference in the time it takes for the car to accelerate, thus to obtain the elapsed time, the foundational basis is set by the relations between Torque/Force, and RPM/Speed of the vehicle. All the calculations are completed by using the data extracted from the car's specifications set (Automobile Catalog). Newton's 2nd Law of Motion is also used to relate Force Output and Speed to the aforementioned relationship, such that data for Force/Speed and consequently, Inverse Force/Speed is tabulated and plotted. The efficiency is then determined through analyzing the area under the graphs which represent the time elapsed. The results conclude that the efficiency of the car is affected adversely when the tire radius decreases upon a fall in tire pressure, and vice versa.

Keywords

Audi A8, vehicle efficiency, tire pressure, speed, acceleration, force, torque, gear ratio

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PROBLEM STATEMENT

This paper is aimed at determining the efficiency for an automobile to accelerate in two separate settings of tire pressure, to evaluate the relationship between the both. The calculations are derived from the torque/RPM of a specific vehicle, thus no exact conclusions can be applied to other cases.

MOTIVATION

The problem covers a broad array of concepts from the STEM sector, as not only does it include the critical-thinking aspect originating from Calculus, but it also involves the theoretical knowledge from Physics. Whereas, for per se the Mechanical Engineering industry, the scenario can help improve the performance of future designs in context to an improved acceleration and higher efficiency. Hence, all these factors make it a very vital component relevant for all three branches of science and mathematics. With the completion of this investigation, the relationship between the tire pressure and overall efficiency of the car can be clearly identified.

MATHEMATICAL DESCRIPTION & SOLUTION APPROACH

Newton's 2nd Law of Motion provides the definitions of Weight and Net Force in terms of acceleration and mass. Using these equations, four separate variables can be obtained and then be used to convert Torque/RPM to a Force Output/Speed relationship.

Weight (w) = Mass (m) × Acceleration of Freefall (g)

$$\rightarrow m = \frac{w}{g}$$

Force Output (F) = Mass of car (m) × Acceleration of Car (a)

$$\rightarrow \boldsymbol{F = \frac{w}{g} \bullet a} \quad \textbf{(Eq. 1)}$$

However, as we know, acceleration is defined as the rate of change of velocity:

Acceleration (a) = Change in Velocity (Δv)/ Change in Time (Δt)

$$\rightarrow \boldsymbol{a = \frac{\Delta v}{\Delta t}} \qquad \textbf{(Eq. 2)}$$

Hence, equations (1) and (2) can be rearranged to get expressions for Force Output and Elapsed time:

Force Output (F) = Mass of car (m) × Change in Velocity (Δv)/ Change in Time (Δt)

$$\rightarrow F = \frac{w}{g} \bullet \frac{\Delta v}{\Delta t}$$

$$\rightarrow \Delta t = \frac{w \bullet \Delta v}{g \bullet F}$$

$$\rightarrow \boldsymbol{t = \int F^{-1} \bullet \frac{w}{g} \bullet \Delta v} \qquad \textbf{(Eq. 3)}$$

To be able to convert the torque-rpm data for the force-speed graphs, it is significant to note that the variables used in the following equations are extracted from the specifications of the 2018 Audi A8 (*Automobile Catalog),* and the values used for the constants are also given in *Figure XII* [Appendix II].

$$\text{Force}_{\text{ Rear Wheels}} = \frac{(\text{Torque}) \times (\text{Differential Ratio}) \times (\text{Ratio for Specific Gear})}{\text{Tire Radius}}$$

$$\rightarrow \boldsymbol{F_{RW} = (T \bullet r_f \bullet r_t) / R} \quad \textbf{(Eq. 4)}$$

$$\rightarrow \boldsymbol{F^{-1} = \frac{w}{g} \bullet \frac{1}{F_{RW}}} \qquad \textbf{(Eq. 5)}$$

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To evaluate speed, the used formula is:

$$\text{Speed} = \frac{(\text{Revolutions per Minute}) \times (\text{Tire Radius}) \times (2\pi)}{(\text{Differential Ratio}) \times (\text{Gear Ratio}) \times (60)}$$

$$\rightarrow v = (R_{PM} \bullet R \bullet 2\pi) / (r_f \bullet r_t \,.\, 60) \quad \textbf{(Eq. 6)}$$

The force acting on the rear wheels is calculated by multiplying the torque from the engine and the total ratio of the output of the wheels from the engine and dividing by the tire radius which cancels out the unit of feet and yields the force output at the wheels. The velocity is then calculated by multiplying the rpm by the radius of the tire and 2π. This is done to convert the value from revolutions per minute to radians per minute. Finally, this value is divided by the differential ratio times the ratio of the specific gear times 60 seconds per minute. The calculations result in the velocity of the vehicle over ground in feet per second (McTighe). With that being said, the graphs for both Force Output (F) against Speed (v), and Inverse Force Output (F^{-1}) against Speed (v), are designed.

The main objective of the paper, *i.e.* the comparison of efficiency in acceleration with different tire pressures can then be easily evaluated based on the difference in the radius of the tire upon change in tire pressure, as both F_{RW} and v are based on the radius, R.

DISCUSSION

The 2018 Audi A8 is an 8-gear performance vehicle with a 3.0 L V6 Diesel Turbo engine. It provides a maximum horsepower of 286 PS and a net torque of 600 Nm. The transmission has a differential ratio of 2.28 and a total weight of 4353 lbs., with a wheel diameter of 2.34ft and a tire width of 0.771ft. The basis of all calculations is best expressed in *Figure 1*, where the 48 data points of torque-rpm, precisely capture the relationship [Appendix I]. The *F/v*

(Figure A) and F^{-1}/v (Figure B) for each gear are then also derived from the same data. This pair of graphs is for when the tire pressure is at 50 psi (Maximum). Therefore, the same process is repeated and two new graphs (Figure C & Figure D) are plotted, for which the tire pressure is 25 psi (Partial).

Using the values for Inverse Force, the elapsed time for both scenarios can be tabulated separately through using Eq. 3. These values for time can then be used to calculate and compare the efficiency by using Eq. 7.

Before the results are looked at, it is necessary to highlight that no external resistive forces such as traction or air resistance, are taken in consideration for the project, thus, values obtained are solely based on the vehicle's operational specifications.

It should also be noted that the values in both the F/v and F^{-1}/v curves are not plotted starting from 0 for velocity. This is because under the minimum speed, the clutch on the vehicle is not fully engaged. Therefore, a portion of the torque produced from the engine is not being delivered to the rear wheels. The maximum speed of the vehicle is also unrealistically high in magnitude because the calculations negate air resistance, external forces of friction (friction between the tires and the road), and internal forces of friction (friction between moving parts within the vehicle) (McTighe).

To understand why the time for acceleration changes in the first place, it is vital to interpret the effects of altering the tire pressure. When the tire pressure is reduced, the overall volume of air inside the tire decreases. As a result, the radius of tire is changed, such that the area in contact with the ground decreases, and thus the contact force decreases.

For a graphical representation, the process for finding Force as a product of Torque is repeated twice; at Max pressure, and at Partial Pressure. The assumption being made is that

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when pressure is halved, the radius of the tire is also halved. Thus, for these two distinct values of R, there are a total of 4 graphs representing this change.

Relationship between Force and Speed at Maximum Tire Pressure (Max Radius)

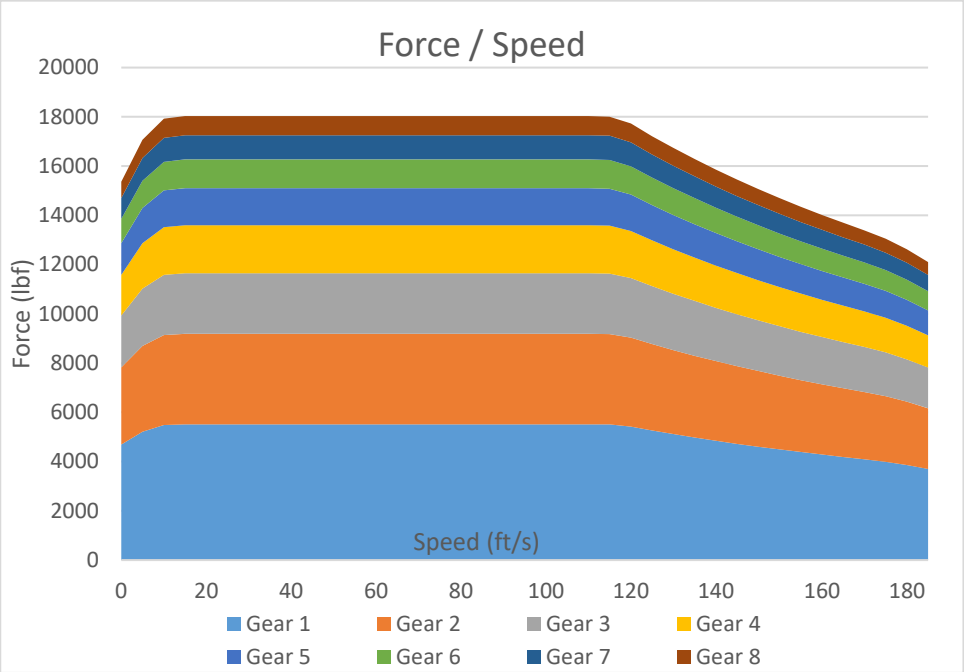

Figure A: A plot of the data tabulated in *Figure VII.*

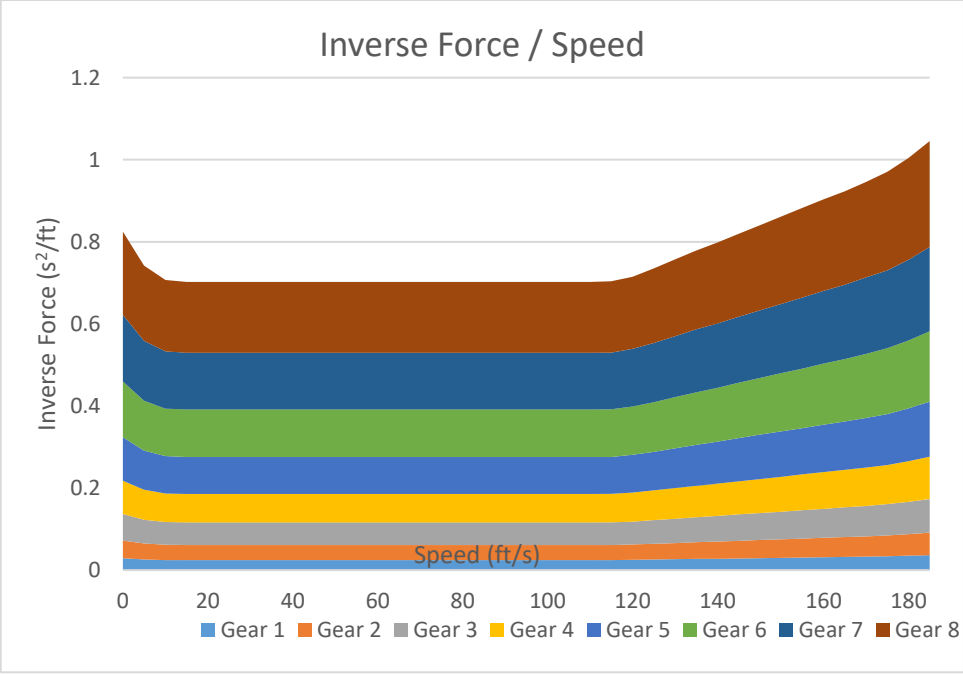

Figure B: A plot of the data tabulated in *Figure VIII.*

Relationship between Force and Speed at Partial Tire Pressure (Radius is halved)

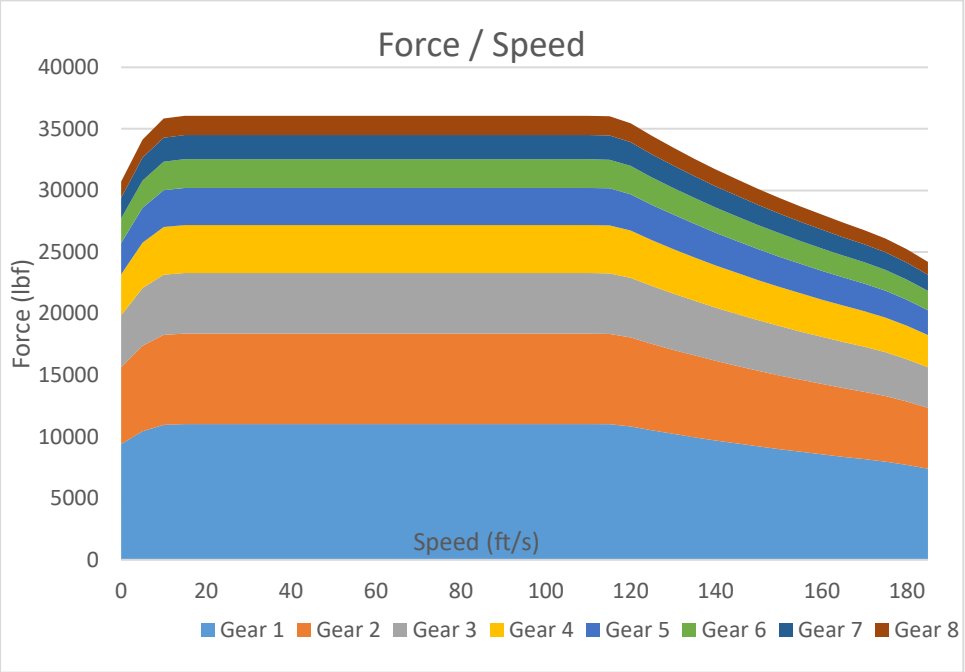

Figure C: A plot of the data tabulated in *Figure IX*.

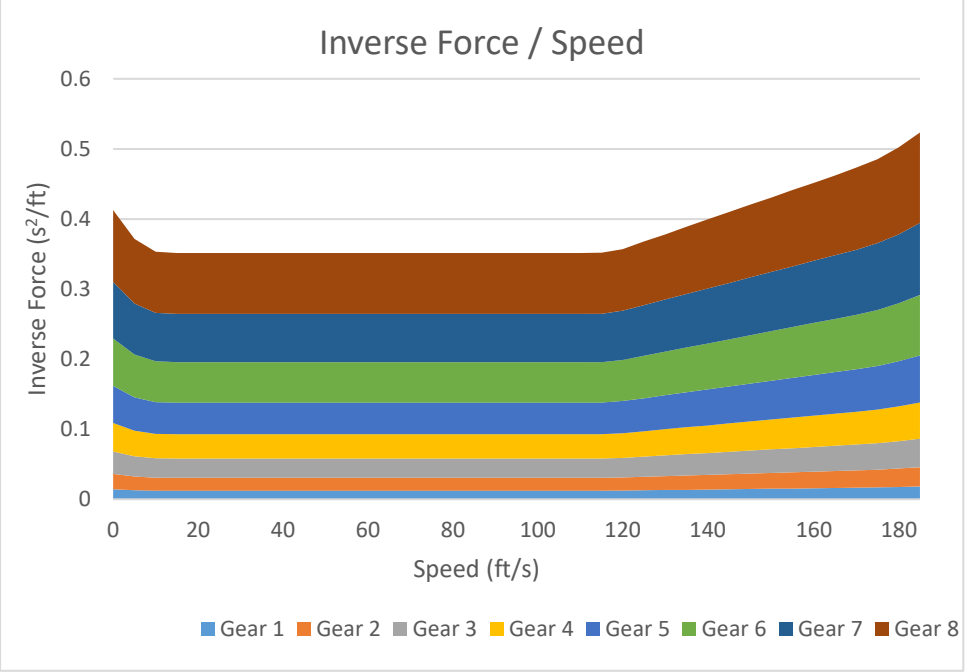

Figure D: A plot of the data tabulated in *Figure X*.

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CONCLUSIONS & RECOMMENDATIONS

Upon analyzing the graphical framework for the project, it is evident that the force acting on the ground is affected when the tire pressure is altered. The area under the graphs verifies the statement as the area, representing time elapsed, is greater for the case with lower tire pressure, therefore, the acceleration is inversely affected (Eq. 2). Hence, when efficiency is determined, it can be concluded that when the tires are at maximum pressure, they are much more efficient as the time taken to accelerate is less compared to the time taken to accelerate when the pressure is halved.

Even though these results apply to the 2018 Audi A8 specifically, the inferences drawn can still be applied to the automobile industry generally, keeping in mind the fundamental findings of the paper as the relationship between efficiency and tire pressure. The main limitation is regarding the exact tire pressures suitable for each car as the torque-rpm relationship is different for every vehicle. A key improvement to this project can be in the form of taking in account factors such as road condition and tire condition to enhance the accuracy of the results.

NOMENCLATURE

Symbol	Quantity	Unit
RPM	Revolutions per Minute	rev min^{-1}
a	Acceleration	ft s^{-2}
HP	Horsepower	PS
T	Torque	lb - ft
F^{-1}	Inverse Force	s^2/ft

F_{RW}	Force on Rear Wheels	*lb* - f
v	Speed	ft s^{-1}
P	Tire Pressure	psi
m	Mass	*lb*
a_g	Acceleration of Gravity	32.2 ft s^{-2}
r_f	Differential Ratio	-
r_t	Gear Ratio	-
R	Tire Radius	ft
t	Time	s

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APPENDIX I

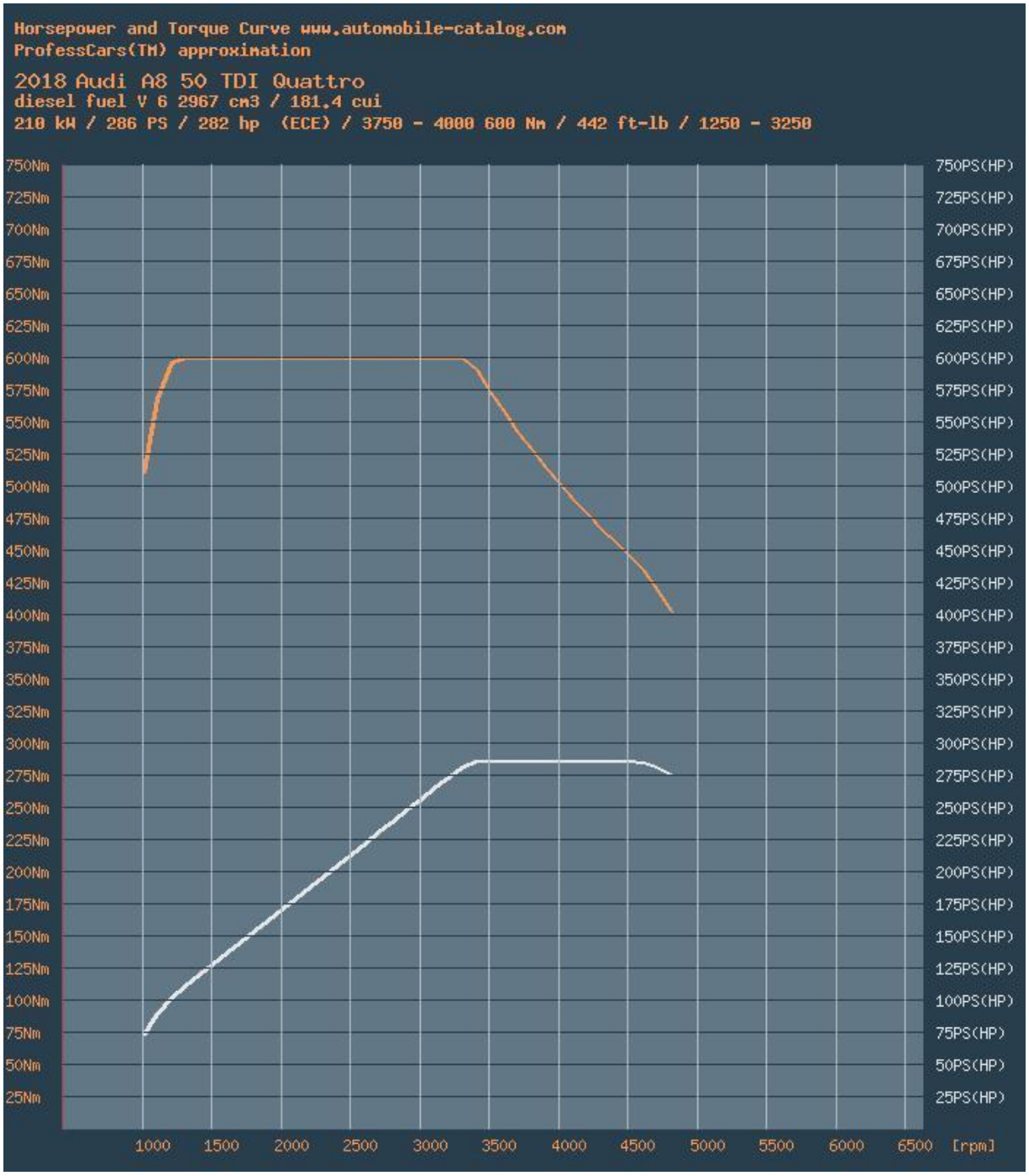

Figure I: The graph above depicts the relationship between RPM, Torque and Horsepower.

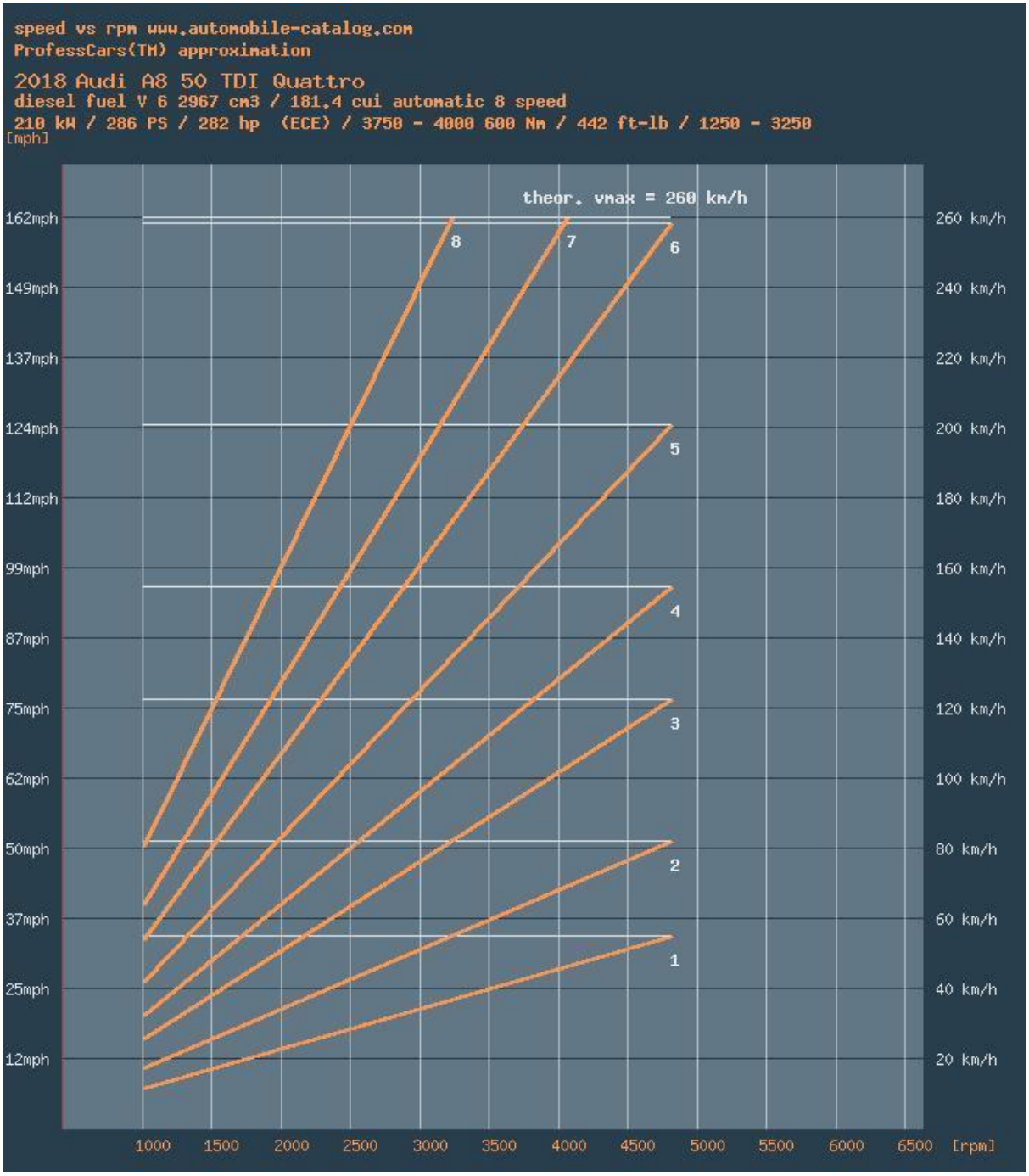

Figure II: The graph above depicts the relationship between Speed and RPM for each gear.

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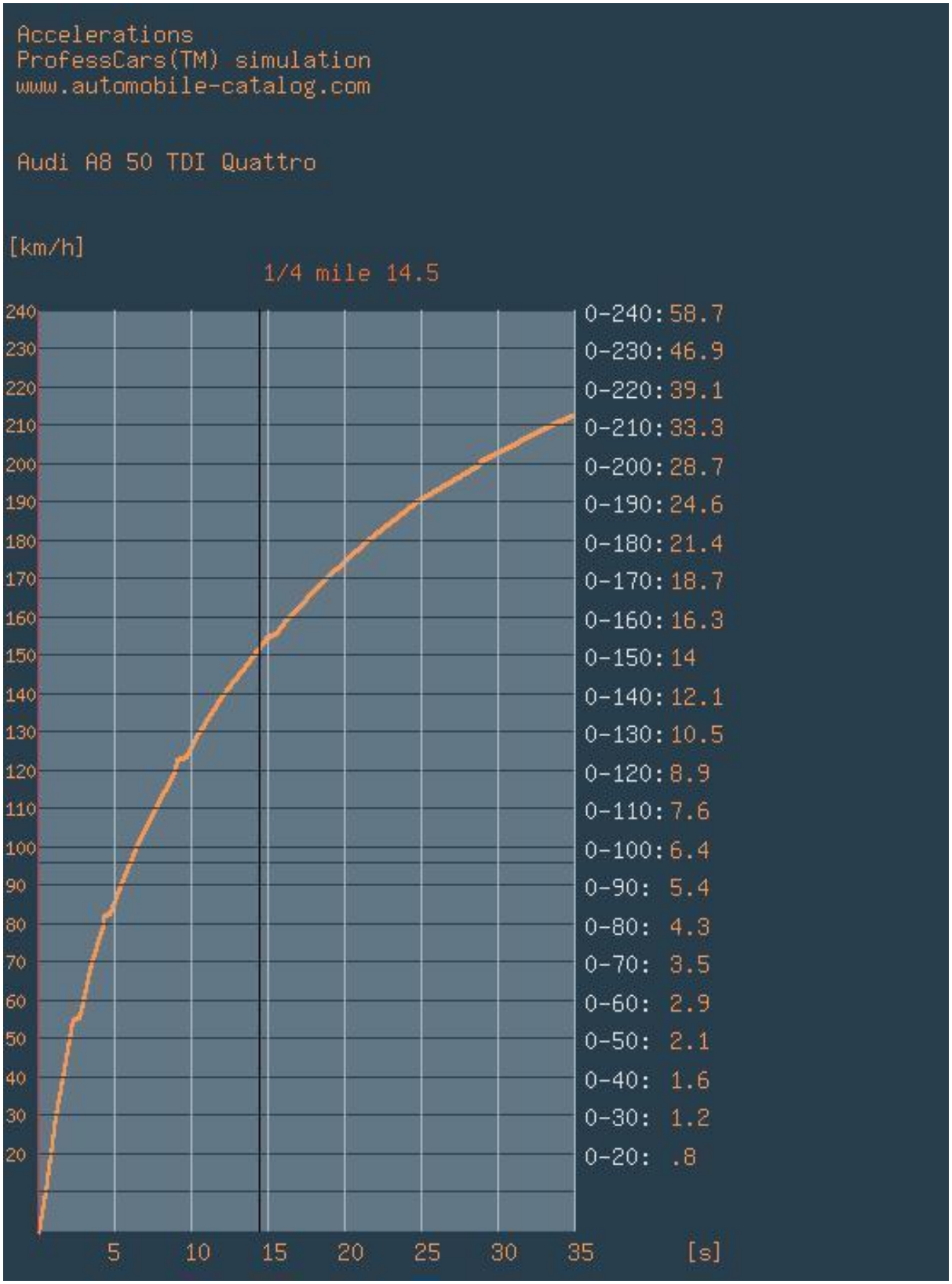

Figure III: The graph above depicts the relationship between Speed and Time, such that the gradient of the curve represents the Acceleration.

APPENDIX II

Figure IV: The table below contains RPM/Torque/HP values for the curve in *Figure I.*

RPM / revs	Torque / (Nm)	Horsepower / PS
1000	511.2	72.8
1100	568	89
1200	596.4	101.9
1300	600	111.1
1400	600	119.6
1500	600	128.2
1600	600	136.7
1700	600	145.3
1800	600	153.8
1900	600	162.4
2000	600	170.9
2100	600	179.5
2200	600	188
2300	600	196.5
2400	600	205.1
2500	600	213.6
2600	600	222.2
2700	600	230.7
2800	600	239.3
2900	600	247.8

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3000	600	256.4
3100	600	264.9
3200	600	273.5
3300	599.3	281.7
3400	589.8	285.6
3500	572.9	285.6
3600	557	285.6
3700	542	285.6
3800	527.7	285.6
3900	514.2	285.6
4000	501.3	285.6
4100	489.1	285.6
4200	477.5	285.6
4300	466.4	285.6
4400	455.8	285.6
4500	445.6	285.6
4600	434.2	284.5
4700	419.8	281
4800	402.7	275.3

Figure V: The table below contains the Acceleration against time values for the curve represented in *Figure III.*

Acceleration / (km / h • s)	Time taken / (s)
0-30	1.2
0-40	1.6
0-50	2.1
0-60	2.9
0-70	3.5
0-80	4.3
0-90	5.4
0-100	6.4
0-110	7.6
0-120	8.9
0-130	10.5
0-140	12.1
0-150	14
0-160	16.3
0-170	18.7
0-180	21.4
0-190	24.6
0-200	28.7
0-210	33.3
0-220	39.1

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0-230	46.9
0-240	58.7
0-250	84.6

Figure VI: The table below contains the Speed (ft/s) and RPM (rev/min) per gear when the tire pressure is kept maximum, correct to 1 decimal place. The values are plotted in the graph in *Figure II*. The values that are highlighted represent the speeds which exceed the car's top speed.

RPM	Gear 1	Gear 2	Gear 3	Gear 4	Gear 5	Gear 6	Gear 7	Gear 8
1000	10.4	15.6	23.2	29.3	38.1	49.0	58.4	73.5
1100	11.4	17.1	25.6	32.4	41.9	53.9	64.2	80.8
1200	12.5	18.7	27.9	35.3	45.7	58.8	70.1	88.1
1300	13.5	20.2	30.3	38.2	49.6	63.7	75.9	95.5
1400	14.6	21.8	32.5	41.1	53.4	68.6	81.7	102.8
1500	15.6	23.4	34.9	44.1	57.2	73.5	87.6	110.2
1600	16.6	25.0	37.2	47.0	61.0	78.4	93.4	117.6
1700	17.7	26.5	39.6	49.9	64.8	83.3	99.2	124.9
1800	18.7	28.1	41.8	52.9	68.6	88.2	105.1	132.2
1900	19.8	29.6	44.2	55.9	72.5	93.0	110.9	139.5
2000	20.8	31.2	46.6	58.8	76.3	98.0	116.8	146.9
2100	21.8	32.7	48.8	61.7	80.1	102.9	122.7	154.3
2200	22.9	34.3	51.2	64.6	83.8	107.8	128.5	161.6
2300	23.9	35.8	53.5	67.6	87.7	112.6	134.3	169.0
2400	25.0	37.5	55.9	70.5	91.5	117.6	140.2	177.2

2500	26.0	39.0	58.1	73.5	95.3	122.5	146.0	183.6
2600	27.1	40.6	60.5	76.4	99.2	127.4	151.8	191.0
2700	28.1	42.1	62.8	79.4	103.0	132.3	157.7	198.3
2800	29.1	43.7	65.2	82.3	106.7	137.2	163.5	205.7
2900	30.2	45.2	67.4	85.2	110.5	142.1	169.3	213.0
3000	31.2	46.8	69.8	88.1	114.4	147.0	175.2	220.4
3100	32.3	48.3	72.1	91.1	118.2	151.9	181.0	227.7
3200	33.3	49.9	74.5	94.1	122.0	156.8	186.8	235.0
3300	34.3	51.4	76.7	97.0	125.9	161.7	192.7	242.4
3400	35.4	53.0	79.1	99.9	129.6	166.6	198.6	249.7
3500	36.4	54.6	81.4	102.9	133.4	171.5	204.4	257.1
3600	37.5	56.1	83.8	105.8	137.2	176.3	210.2	264.5
3700	38.5	57.7	86.0	108.7	141.1	181.3	216.1	271.8
3800	39.5	59.2	88.4	111.6	144.9	186.2	221.9	279.1
3900	40.6	60.8	90.8	114.6	148.7	191.1	227.7	286.4
4000	41.6	62.3	93.0	117.6	152.5	195.9	233.6	293.8
4100	42.7	63.9	95.4	120.5	156.3	200.9	239.4	301.2
4200	43.7	65.4	97.7	123.4	160.1	205.8	245.2	308.5
4300	44.7	67.0	100.1	126.4	164.0	210.7	251.1	315.9
4400	45.7	68.6	102.3	129.3	167.8	215.5	256.9	323.2
4500	46.8	70.2	104.7	132.2	171.6	220.5	262.7	330.5
4600	47.8	71.7	107.0	135.2	175.3	225.4	268.6	337.9
4700	48.8	73.3	109.4	138.2	179.2	230.3	274.5	345.2
4800	49.9	74.8	111.6	141.1	183.0	235.1	280.3	352.6

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Figure VII: The table below contains the conversion to Force (lb f) from Torque (lb –ft), for each gear, when the tire pressure is kept at a maximum level. Values are correct to 1 decimal place.

Torque	Force							
-	Gear 1	Gear 2	Gear 3	Gear 4	Gear 5	Gear 6	Gear 7	Gear 8
511.2	4696.0	3131.0	2098.0	1660.6	1280.1	996.2	835.8	664.5
568	5217.8	3478.9	2331.1	1845.2	1422.3	1106.9	928.7	738.3
596.4	5478.7	3652.8	2447.6	1937.4	1493.4	1162.2	975.1	775.2
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
600	5511.8	3674.9	2462.4	1949.1	1502.5	1169.2	981.0	779.9
599.3	5505.3	3670.6	2459.5	1946.8	1500.7	1167.9	979.8	779.0
589.8	5418.1	3612.4	2420.5	1916.0	1476.9	1149.4	964.3	766.6
572.9	5262.8	3508.9	2351.2	1861.1	1434.6	1116.4	936.7	744.7
557	5116.7	3411.5	2285.9	1809.4	1394.8	1085.4	910.7	724.0

542	4979.0	3319.7	2224.4	1760.7	1357.2	1056.2	886.2	704.5
527.7	4847.6	3232.1	2165.7	1714.2	1321.4	1028.3	862.8	685.9
514.2	4723.6	3149.4	2110.3	1670.4	1287.6	1002.0	840.7	668.4
501.3	4605.1	3070.4	2057.3	1628.5	1255.3	976.9	819.6	651.6
489.1	4493.0	2995.6	2007.3	1588.8	1224.8	953.1	799.7	635.7
477.5	4386.4	2924.6	1959.7	1551.2	1195.7	930.5	780.7	620.7
466.4	4284.5	2856.6	1914.1	1515.1	1167.9	908.9	762.6	606.2
455.8	4187.1	2791.7	1870.6	1480.7	1141.4	888.2	745.2	592.4
445.6	4093.4	2729.2	1828.7	1447.5	1115.8	868.3	728.5	579.2
434.2	3988.7	2659.4	1782.0	1410.5	1087.3	846.1	709.9	564.4
419.8	3856.4	2571.2	1722.9	1363.7	1051.2	818.1	686.4	545.7
402.7	3699.3	2466.5	1652.7	1308.2	1008.4	784.7	658.4	523.4

Figure VIII: The table below contains the conversion to Inverse Force (s^2/ft) from Torque (lb –ft), for each gear, when the tire pressure is kept at a maximum level. Values are correct to 3 significant figures.

Torque	Inverse Force							
-	Gear 1	Gear 2	Gear 3	Gear 4	Gear 5	Gear 6	Gear 7	Gear 8
511.2	0.0288	0.0432	0.0644	0.0814	0.106	0.136	0.162	0.203
568	0.0259	0.0389	0.0580	0.0733	0.095	0.122	0.146	0.183
596.4	0.0247	0.0370	0.0552	0.0698	0.091	0.116	0.139	0.174
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173

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600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
600	0.0245	0.0368	0.0549	0.0694	0.090	0.116	0.138	0.173
599.3	0.0246	0.0368	0.0550	0.0694	0.090	0.116	0.138	0.174
589.8	0.0250	0.0374	0.0559	0.0706	0.092	0.118	0.140	0.176
572.9	0.0257	0.0385	0.0575	0.0726	0.094	0.121	0.144	0.182
557	0.0264	0.0396	0.0591	0.0747	0.097	0.125	0.148	0.187
542	0.0272	0.0407	0.0608	0.0768	0.100	0.128	0.153	0.192
527.7	0.0279	0.0418	0.0624	0.0789	0.102	0.131	0.157	0.197
514.2	0.0286	0.0429	0.0641	0.0809	0.105	0.135	0.161	0.202
501.3	0.0294	0.0440	0.0657	0.0830	0.108	0.138	0.165	0.207
489.1	0.0301	0.0451	0.0673	0.0851	0.110	0.142	0.169	0.213
477.5	0.0308	0.0462	0.0690	0.0871	0.113	0.145	0.173	0.218
466.4	0.0316	0.0473	0.0706	0.0892	0.116	0.149	0.177	0.223
455.8	0.0323	0.0484	0.0723	0.0913	0.118	0.152	0.181	0.228
445.6	0.0330	0.0495	0.0739	0.0934	0.121	0.156	0.186	0.233
434.2	0.0339	0.0508	0.0759	0.0958	0.124	0.160	0.190	0.240
419.8	0.0351	0.0526	0.0785	0.0991	0.129	0.165	0.197	0.248
402.7	0.0365	0.0548	0.0818	0.1033	0.134	0.172	0.205	0.258

Figure IX: The table below contains the Speed (ft/s) and RPM (rev/min) per gear when the tire pressure is halved, correct to 1 decimal place. The values that are highlighted represent the speeds which exceed the car's top speed.

RPM	Gear 1	Gear 2	Gear 3	Gear 4	Gear 5	Gear 6	Gear 7	Gear 8
1000	5.70	8.55	12.8	16.1	20.9	26.9	32.0	40.3
1100	6.27	9.41	14.0	17.7	23.0	29.6	35.2	44.3
1200	6.84	10.26	15.3	19.3	25.1	32.3	38.4	48.4
1300	7.41	11.12	16.6	21.0	27.2	34.9	41.6	52.4
1400	7.98	11.97	17.9	22.6	29.3	37.6	44.9	56.4
1500	8.55	12.83	19.1	24.2	31.4	40.3	48.1	60.4
1600	9.12	13.68	20.4	25.8	33.5	43.0	51.3	64.5
1700	9.69	14.54	21.7	27.4	35.6	45.7	54.5	68.5
1800	10.26	15.39	23.0	29.0	37.7	48.4	57.7	72.5
1900	10.83	16.25	24.3	30.6	39.7	51.1	60.9	76.6
2000	11.40	17.10	25.5	32.2	41.8	53.8	64.1	80.6
2100	11.97	17.96	26.8	33.9	43.9	56.4	67.3	84.6
2200	12.54	18.81	28.1	35.5	46.0	59.1	70.5	88.7
2300	13.11	19.67	29.4	37.1	48.1	61.8	73.7	92.7
2400	13.69	20.53	30.6	38.7	50.2	64.5	76.9	96.7
2500	14.26	21.38	31.9	40.3	52.3	67.2	80.1	100.7
2600	14.83	22.24	33.2	41.9	54.4	69.9	83.3	104.8
2700	15.40	23.09	34.5	43.5	56.5	72.6	86.5	108.8
2800	15.97	23.95	35.7	45.1	58.6	75.3	89.7	112.8
2900	16.54	24.80	37.0	46.8	60.7	78.0	92.9	116.9
3000	17.11	25.66	38.3	48.4	62.8	80.6	96.1	120.9
3100	17.68	26.51	39.6	50.0	64.8	83.3	99.3	124.9

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3200	18.25	27.37	40.8	51.6	66.9	86.0	102.5	129.0
3300	18.82	28.22	42.1	53.2	69.0	88.7	105.7	133.0
3400	19.39	29.08	43.4	54.8	71.1	91.4	108.9	137.0
3500	19.96	29.93	44.7	56.4	73.2	94.1	112.1	141.0
3600	20.53	30.79	45.9	58.0	75.3	96.8	115.3	145.1
3700	21.10	31.64	47.2	59.7	77.4	99.5	118.5	149.1
3800	21.67	32.50	48.5	61.3	79.5	102.1	121.7	153.1
3900	22.24	33.35	49.8	62.9	81.6	104.8	124.9	157.2
4000	22.81	34.21	51.1	64.5	83.7	107.5	128.2	161.2
4100	23.38	35.06	52.3	66.1	85.8	110.2	131.4	165.2
4200	23.95	35.92	53.6	67.7	87.9	112.9	134.6	169.3
4300	24.52	36.77	54.9	69.3	89.9	115.6	137.8	173.3
4400	25.09	37.63	56.2	70.9	92.0	118.3	141.0	177.3
4500	25.66	38.49	57.4	72.6	94.1	121.0	144.2	181.3
4600	26.23	39.34	58.7	74.2	96.2	123.6	147.4	185.4
4700	26.80	40.20	60.0	75.8	98.3	126.3	150.6	189.4
4800	27.37	41.05	61.3	77.4	100.4	129.0	153.8	193.4

Figure X: The table below contains the conversion to Force (lb f) from Torque (lb –ft), for each gear, when the tire pressure is halved. Values are correct to 1 decimal place.

Torque	Force							
-	Gear 1	Gear 2	Gear 3	Gear 4	Gear 5	Gear 6	Gear 7	Gear 8
511.2	9392.0	6262.0	4195.9	3321.3	2560.2	1992.4	1671.6	1328.9
568	10435.6	6957.8	4662.1	3690.3	2844.7	2213.7	1857.3	1476.6
596.4	10957.4	7305.7	4895.3	3874.8	2986.9	2324.4	1950.2	1550.4

600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
600	11023.5	7349.8	4924.8	3898.2	3004.9	2338.5	1962.0	1559.8
599.3	11010.6	7341.2	4919.1	3893.7	3001.4	2335.7	1959.7	1557.9
589.8	10836.1	7224.8	4841.1	3831.9	2953.8	2298.7	1928.6	1533.2
572.9	10525.6	7017.8	4702.4	3722.1	2869.2	2232.8	1873.4	1489.3
557	10233.5	6823.1	4571.9	3618.8	2789.6	2170.9	1821.4	1448.0
542	9957.9	6639.3	4448.7	3521.4	2714.4	2112.4	1772.3	1409.0
527.7	9695.2	6464.1	4331.4	3428.5	2642.8	2056.7	1725.6	1371.8
514.2	9447.1	6298.8	4220.6	3340.8	2575.2	2004.1	1681.4	1336.7
501.3	9210.1	6140.7	4114.7	3257.0	2510.6	1953.8	1639.2	1303.2
489.1	8986.0	5991.3	4014.5	3177.7	2449.5	1906.2	1599.3	1271.5
477.5	8772.9	5849.2	3919.3	3102.3	2391.4	1861.0	1561.4	1241.3
466.4	8568.9	5713.2	3828.2	3030.2	2335.8	1817.8	1525.1	1212.4

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455.8	8374.2	5583.4	3741.2	2961.3	2282.7	1776.5	1490.4	1184.9
445.6	8186.8	5458.4	3657.5	2895.1	2231.7	1736.7	1457.1	1158.4
434.2	7977.3	5318.8	3563.9	2821.0	2174.6	1692.3	1419.8	1128.7
419.8	7712.8	5142.4	3445.7	2727.5	2102.4	1636.1	1372.7	1091.3
402.7	7398.6	4932.9	3305.4	2616.4	2016.8	1569.5	1316.8	1046.9

Figure XI: The table below contains the conversion to Inverse Force (s^2/ft) from Torque (lb – ft), for each gear, when the tire pressure is halved. Values are correct to 3 significant figures.

Torque	Inverse Force							
-	Gear 1	Gear 2	Gear 3	Gear 4	Gear 5	Gear 6	Gear 7	Gear 8
511.2	0.0144	0.0216	0.0322	0.0407	0.0528	0.0679	0.0809	0.102
568	0.0130	0.0194	0.0290	0.0366	0.0475	0.0611	0.0728	0.092
596.4	0.0123	0.0185	0.0276	0.0349	0.0453	0.0582	0.0693	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087

600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
600	0.0123	0.0184	0.0275	0.0347	0.0450	0.0578	0.0689	0.087
599.3	0.0123	0.0184	0.0275	0.0347	0.0450	0.0579	0.0690	0.087
589.8	0.0125	0.0187	0.0279	0.0353	0.0458	0.0588	0.0701	0.088
572.9	0.0128	0.0193	0.0287	0.0363	0.0471	0.0605	0.0722	0.091
557	0.0132	0.0198	0.0296	0.0374	0.0485	0.0623	0.0742	0.093
542	0.0136	0.0204	0.0304	0.0384	0.0498	0.0640	0.0763	0.096
527.7	0.0139	0.0209	0.0312	0.0394	0.0512	0.0657	0.0783	0.099
514.2	0.0143	0.0215	0.0320	0.0405	0.0525	0.0675	0.0804	0.101
501.3	0.0147	0.0220	0.0329	0.0415	0.0538	0.0692	0.0825	0.104
489.1	0.0150	0.0226	0.0337	0.0425	0.0552	0.0709	0.0845	0.106
477.5	0.0154	0.0231	0.0345	0.0436	0.0565	0.0726	0.0866	0.109
466.4	0.0158	0.0237	0.0353	0.0446	0.0579	0.0744	0.0886	0.111
455.8	0.0161	0.0242	0.0361	0.0457	0.0592	0.0761	0.0907	0.114
445.6	0.0165	0.0248	0.0370	0.0467	0.0606	0.0778	0.0928	0.117
434.2	0.0169	0.0254	0.0379	0.0479	0.0622	0.0799	0.0952	0.120
419.8	0.0175	0.0263	0.0392	0.0496	0.0643	0.0826	0.0985	0.124
402.7	0.0183	0.0274	0.0409	0.0517	0.0670	0.0861	0.103	0.129

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Figure XII: The table below contains the specifications of the 2018 Audi A8 that were used throughout the paper.

Differential Ratio (r_f)	Gear (#)	Gear Ratio (r_t)	Tire Radius (ft)
2.280	1	4.714	1.170 (Max)
	2	3.143	0.585 (Partial)
	3	2.106	
	4	1.667	
	5	1.285	
	6	1.000	
	7	0.839	
	8	0.667	