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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 2\textsuperscript{nd} 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 \( (w) = \text{Mass} \ (m) \times \text{Acceleration of Freefall} \ (g) \)

\[
\rightarrow m = \frac{w}{g}
\]
Force Output \((F)\) = Mass of car \((m)\) \times Acceleration of Car \((a)\)

\[ F = \frac{w}{g} \cdot a \]  \hspace{1cm} (Eq. 1)

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

Acceleration \((a)\) = Change in Velocity \((\Delta v)\)/ Change in Time \((\Delta t)\)

\[ a = \frac{\Delta v}{\Delta t} \]  \hspace{1cm} (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 \((m)\) \times Change in Velocity \((\Delta v)\)/ Change in Time \((\Delta t)\)

\[ F = \frac{w}{g} \cdot \frac{\Delta v}{\Delta t} \]

\[ \Delta t = \frac{w \cdot \Delta v}{g \cdot F} \]

\[ t = \int F^{-1} \cdot \frac{w}{g} \cdot \Delta v \] \hspace{1cm} (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].

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

\[ F_{RW} = \frac{T \cdot r_f \cdot r_t}{R} \] \hspace{1cm} (Eq. 4)

\[ F^{-1} = \frac{w}{g} \cdot \frac{1}{F_{RW}} \] \hspace{1cm} (Eq. 5)
To evaluate speed, the used formula is:

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

\[\rightarrow v = \frac{(R_{PM} \cdot R \cdot 2\pi)}{(r_f \cdot r_t \cdot 60)} \quad (\text{Eq. 6})\]

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 \(2\pi\). 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, \textit{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 2.34 ft and a tire width of 0.771 ft. The basis of all calculations is best expressed in \textit{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
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)

![Force / Speed Graph](image)

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

![Inverse Force / Speed Graph](image)

**Figure D:** A plot of the data tabulated in *Figure X.*
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   | s²/ft |
| $F_{RW}$  | Force on Rear Wheels | $lb$ | $\text{f}$ |
|----------|-----------------------|------|-----------|
| $v$      | Speed                | $\text{ft s}^{-1}$ |           |
| $P$      | Tire Pressure        | psi  |           |
| $m$      | Mass                 | $\text{lb}$ |           |
| $a_g$    | Acceleration of Gravity | $\text{32.2 ft s}^{-2}$ | |
| $r_f$    | Differential Ratio   | -    |           |
| $r_t$    | Gear Ratio           | -    |           |
| $R$      | Tire Radius          | $\text{ft}$ |           |
| $t$      | Time                 | $\text{s}$ |           |

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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.
Figure III: The graph above depicts the relationship between Speed and Time, such that the gradient of the curve represents the Acceleration.
**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           |
| RPM  | Pressure | Efficiency |
|------|----------|------------|
| 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             |
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|       |      |        |      |        |      |        |
| Power (W) | 2500  | 2600  | 2700  | 2800  | 2900  | 3000  | 3100  | 3200  | 3300  | 3400  | 3500  | 3600  | 3700  | 3800  | 3900  | 4000  | 4100  | 4200  | 4300  | 4400  | 4500  | 4600  | 4700  | 4800  |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 2500     | 26.0  | 27.1  | 28.1  | 29.1  | 30.2  | 31.2  | 32.3  | 33.3  | 34.3  | 35.4  | 36.4  | 37.5  | 38.5  | 39.5  | 40.6  | 41.6  | 42.7  | 43.7  | 44.7  | 45.7  | 46.8  | 47.8  | 48.8  | 49.9  |
| 2600     | 39.0  | 40.6  | 42.1  | 43.7  | 45.2  | 46.8  | 48.3  | 49.9  | 51.4  | 53.0  | 54.6  | 56.1  | 57.7  | 59.2  | 60.8  | 62.3  | 63.9  | 65.4  | 67.0  | 68.6  | 70.2  | 71.7  | 73.3  | 74.8  |
| 2700     | 58.1  | 60.5  | 62.8  | 65.2  | 67.4  | 69.8  | 72.1  | 74.5  | 76.7  | 79.1  | 81.4  | 83.8  | 86.0  | 88.4  | 90.8  | 93.0  | 95.4  | 97.7  | 100.1 | 102.3 | 104.7 | 107.0 | 109.4 |
| 2800     | 73.5  | 76.4  | 79.4  | 82.3  | 85.2  | 88.1  | 91.1  | 94.1  | 97.0  | 99.9  | 102.9 | 105.8 | 108.7 | 111.6 | 114.6 | 117.6 | 120.5 | 123.4 | 126.4 | 129.3 | 132.2 | 135.2 | 138.2 |
| 2900     | 95.3  | 99.2  | 103.0 | 106.7 | 110.5 | 114.4 | 118.2 | 122.0 | 125.9 | 129.6 | 133.4 | 137.2 | 141.1 | 144.9 | 148.7 | 152.5 | 156.3 | 160.1 | 164.0 | 167.8 | 171.6 | 175.3 | 179.2 |
| 3000     | 122.5 | 127.4 | 132.3 | 137.2 | 142.1 | 147.0 | 151.9 | 156.8 | 161.7 | 166.6 | 171.5 | 176.3 | 181.3 | 186.2 | 191.1 | 195.9 | 200.9 | 205.8 | 210.7 | 215.5 | 220.5 | 225.4 | 230.3 |
| 3100     | 146.0 | 151.8 | 157.7 | 163.5 | 169.3 | 175.2 | 181.0 | 186.8 | 192.7 | 198.6 | 204.4 | 210.2 | 216.1 | 221.9 | 227.7 | 233.6 | 239.4 | 245.2 | 251.1 | 256.9 | 262.7 | 268.6 | 274.5 |
| 3200     | 183.6 | 191.0 | 198.3 | 205.7 | 213.0 | 220.4 | 227.7 | 235.0 | 242.4 | 249.7 | 257.1 | 264.5 | 271.8 | 279.1 | 286.4 | 293.8 | 301.2 | 308.5 | 315.9 | 323.2 | 330.5 | 337.9 | 345.2 |
| 3300     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 3400     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 3500     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 3600     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 3700     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 3800     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 3900     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 4000     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 4100     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 4200     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 4300     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 4400     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 4500     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 4600     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 4700     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 4800     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
**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 |
| 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 |
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 | 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 |
| 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 | 0.173 |
| 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  |
### Table: Conversion to Force (lb f) from Torque (lb – ft), for each gear, when the tire pressure is halved.

| Torque | Gear 1 | Gear 2 | Gear 3 | Gear 4 | Gear 5 | Gear 6 | Gear 7 | Gear 8 |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 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.
| 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 |
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 | 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  |
Figure XII: The table below contains the specifications of the 2018 Audi A8 that were used throughout the paper.

| Differential Ratio ($r_t$) | Gear (#) | Gear Ratio ($r_i$) | 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             |                  |