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Technical Report

The Effect of Tire Inflation Pressure on Vehicle Fuel Economy

by

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Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air, Noise and Radiation
U.S. Environmental Protection Agency

Purpose

This study investigates the extent of underinflation of in-use automobile tires and predicts the potential fuel conservation which would result if this underinflation were corrected.

The report further recommends a simple approach, applicable to a rapid emissions or safety inspection lane which would reduce the percentage of vehicles with underinflated tires and would significantly reduce U.S. annual gasoline consumption.

Introduction

The technical literature indicates that most vehicles on the road are operated with underinflated tires. Since tire energy dissipation increases at lower tire inflation pressure and vehicle fuel consumption increases with increasing tire energy dissipation, a vehicle with underinflated tires will consume more fuel than it would with properly inflated tires. Consequently, a program to increase average tire inflation pressure on in-use vehicles would result in significant fuel savings.

The 1977 emission factors program conducted by the EPA MVEL provided an opportunity to gather tire inflation data from in-use vehicles. The remainder of this report discusses the analysis of these data and proposes a simple approach to increase tire inflation pressure and reduce U.S. fuel consumption.

Discussion

The vehicles tested in the 1977 emission factors program were chosen from vehicle registration lists for six different cities. These six cities; Chicago, Houston, Phoenix, St. Louis, Denver, and Washington, D.C.; represent a broad cross section of the different climates and driving conditions encountered in the United States. Test vehicles were selected on the basis of make and model year to give a sample that was representative of the types of vehicles actually on the road at the time of the test. Thus the data base can be considered to represent a microcosm of the United States with regard to both vehicle population and operating conditions.

All tire pressure data were obtained after the vehicle equilibrated at the test temperature of approximately 76° F. since the vehicles tested in this program were allowed to stand indoors at the test temperature for at least eleven hours prior to the test as required by the Federal Test Procedure for measurement of vehicle emissions. A correction factor was then applied to the measured pressure to correct it to the pressure which would have been obtained at the mean outside temperature for the month and location of the test.

This approach of measuring all pressures at the same temperature has some advantage over the more common approach of measuring pressures on the street, because measurements will not be affected by daily variations of the ambient temperature. Consequently, data obtained by this approach may be more representative of the average inflation characteristics of the tire. The correction formula used was the simple ideal gas relation given by:

$$Pcor = Pmea + \frac{Pmea + 14.7}{Tlab} (Tcor - Tlab)$$

where:

Pcor = corrected pressure psig

Pmea = measured pressure at lab temperature psig

Pmea + 14.7 = measured absolute pressure

Tlab = absolute temperature of lab °K

Tcor = mean outside temperature of test city during month of test °K

This ideal gas relation is nearly exact for the temperatures and pressures encountered in this test and is well within the accuracy of the tire inflation pressure gauge.

The data were reviewed to identify any entries that were apparently incorrect. This was considered desireable because the large size of the data base provided opportunity for key punch or other transcribing errors. All records that included either a blank or an indicated pressure of zero were removed since these were assumed to originate from non-entered data fields. Vehicles with recommended pressures greater than 32 psi were also excluded. It was assumed that either these data were in error or that they were obtained from extra load tires that were not representative of typical automobile tires since passenger car tires in use at that time did not have recommended pressures greater than 32 psi.

This screening rejected only about two percent of the data, leaving 1962 of the original 2,042 vehicles in the data base. The large remaining sample size and the small rejection percentage both indicate that the data are reliable.

Data Analysis

All corrected tire inflation pressure data described in the previous section were analyzed to determine their mean values. This analysis is summarized in table 1.

The data show that the average front tire has a recommended inflation pressure of 26.0 psi but is only inflated to 24.9 psi so

Table 1

Variable	Number	Minimum	Maximum	Mean	Std. Dev.
1. FSPEC	1962	20.000	32.000	25.958	2.3217
2. RSPEC	1962	18.000	32.000	27.318	2.8588
3. FPRES	1962	10.000	43.000	24.854	3.9902
4. RPRES	1962	11.000	46.000	24.733	3.9114
5. FDIF	1962	-19.000	18.000	1.1040	4.4263
6. RDIF	1962	-22.000	18.000	2.5846	4.4834

FSPEC - Front tire recommended pressure
RSPEC - Rear tire recommended pressure
FPRES - Front tire measured pressure
RPRES - Rear tire measured pressure
FDIF - Front tire recommended pressure minus measured pressure
RDIF - Rear tire recommended pressure minus measured pressure

that the average underinflation is 1.1 psi. For rear tires the average underinflation pressure is 2.6 psi. Overall the average tire is underinflated by 1.8 psi. This compares well with an SAE paper by Viergutz et al. that found an overall average tire underinflation of 1.4 psi on cars tested in a Chicago parking lot.1/ Our data shows average underinflation to be slightly greater than reported in Viergutz's paper because most of his data was obtained in the summer when underinflation is less of a problem. These results are similar to those reported from other surveys.2/

Results of recent EPA tests demonstrate that vehicle fuel consumption decreases about 0.4 percent for each psi increase in the tire inflation pressure in the normal operating range.3/ Consequently, in-use vehicles presently consume about 0.7 percent more fuel than they would if all tires were inflated to manufactures specifications. For the present vehicle fleet, this represents a possible fuel savings of 36,000 barrels of fuel per day. This is based on U.S. light-duty vehicle consumption of 5.22 million barrels of fuel per day.4/

Of course, not all passenger car tires are underinflated. Figures 1 and 2 are histograms showing the distribution of tire inflation pressures around recommended pressures for front and rear tires. These figures show that many tires are, in fact inflated to a pressure greater than the recommended pressure. As table 2 clearly shows these tires offset some of the effect of the underinflated tires.

Table 2 shows that 57 percent of all front tires and 68 percent of all rear tires are underinflated. If only underinflated tires are considered, front tires are underinflated by an average of 4.1 psi and rear tires are underinflated by an average of 4.9 psi. Overall 63 percent of all tires are underinflated, and the average amount of underinflation is 4.5 psi.

This suggests a scheme for correcting inflation pressure that would save even more fuel than inflating all tires to the recommended pressure. If the pressure of all underinflated tires were increased to the recommended pressure but the pressure of tires above the recommended inflation pressure were left unchanged, the average tire pressure would be 27.6 psi, which would be an increase of 2.8 psi over the present average inflation pressure of 24.8 psi. This strategy would lower fuel consumption by 1.1 percent and result in a fuel savings of 57,000 barrels per day.

A program to increase tire pressure could easily be incorporated into a vehicle inspection lane program. Experience with previous inspection lane programs indicates that it is important to keep the test time for each vehicle to a minimum. Therefore, a strategy that is simpler than inflating each tire to its recommended pressure is desired.

The simplest method would be to use a pressure hose that was maintained at a constant pressure and that had a check valve to

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HISTOGRAM

MIDPOINT     COUNT FOR 5.FDIF  (EACH X= 5)

-22.000        0 +
-21.000        0 +
-20.000        0 +
-19.000        1 +X
-18.000        0 +
-17.000        0 +
-16.000        1 +X
-15.000        0 +
-14.000        2 +X
-13.000        5 +X
-12.000        3 +X
-11.000        4 +X
-10.000        7 +XX
-9.0000       11 +XXX
-8.0000       16 +XXXX
-7.0000       32 +XXXXXXX
-6.0000       43 +XXXXXXXXX
-5.0000       72 +XXXXXXXXXXXXXXX
-4.0000       92 +XXXXXXXXXXXXXXXXXXX
-3.0000      106 +XXXXXXXXXXXXXXXXXXXXXX
-2.0000      116 +XXXXXXXXXXXXXXXXXXXXXXXX
-1.0000      156 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 0.          185 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 1.0000      173 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 2.0000      196 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 3.0000      189 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 4.0000      148 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 5.0000      114 +XXXXXXXXXXXXXXXXXXXXXXX
 6.0000       97 +XXXXXXXXXXXXXXXXXXXX
 7.0000       60 +XXXXXXXXXXXX
 8.0000       45 +XXXXXXXXX
 9.0000       32 +XXXXXXX
 10.000       17 +XXXX
 11.000       17 +XXXX
 12.000        8 +XX
 13.000        3 +X
 14.000        5 +X
 15.000        3 +X
 16.000        0 +
 17.000        1 +X
 18.000        1 +X
```

Figure 1
Distribution of Front Tire Pressure
around Recommended Pressure

> 0 less than recommended
< 0 greater than recommended

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HISTOGRAM

MIDPOINT     COUNT FOR 6.RDIF  (EACH X= 5)

-22.000        1 +X
-21.000        0 +
-20.000        0 +
-19.000        0 +
-18.000        0 +
-17.000        0 +
-16.000        0 +
-15.000        1 +X
-14.000        0 +
-13.000        0 +
-12.000        1 +X
-11.000        0 +
-10.000        6 +XX
-9.0000        5 +X
-8.0000        8 +XX
-7.0000       18 +XXXX
-6.0000       33 +XXXXXXX
-5.0000       42 +XXXXXXXXX
-4.0000       58 +XXXXXXXXXXXX
-3.0000       61 +XXXXXXXXXXXXX
-2.0000       89 +XXXXXXXXXXXXXXXXXX
-1.0000      129 +XXXXXXXXXXXXXXXXXXXXXXXXXX
 0.          167 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 1.0000      172 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 2.0000      180 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 3.0000      170 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 4.0000      187 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 5.0000      162 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 6.0000      123 +XXXXXXXXXXXXXXXXXXXXXXXXX
 7.0000       93 +XXXXXXXXXXXXXXXXXXX
 8.0000       69 +XXXXXXXXXXXXXX
 9.0000       66 +XXXXXXXXXXXXXX
 10.000       42 +XXXXXXXXX
 11.000       20 +XXXX
 12.000       28 +XXXXXX
 13.000       13 +XXX
 14.000        7 +XX
 15.000        4 +X
 16.000        3 +X
 17.000        1 +X
 18.000        2 +X
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Figure 2
Distribution of Rear Tire Pressure
around Recommended Pressure

> 0 less than recommended
< 0 greater than recommended

Table 2

Tires Inflated over Recommended Pressure

	Number	Minimum	Maximum	Mean	Std. Dev.
FPRES	667	22.0	43.0	28.4	2.85
RPRES	452	22.0	46.0	28.6	2.94

Underinflated Tires

	Number	Minimum	Maximum	Mean	Std. Dev.
FPRES	1110	10.0	31.0	22.58	3.13
RPRES	1343	11.0	31.0	23.25	3.37

Measured front and rear pressures for tires inflated above and below recommended inflation pressure.

insure no air would ever be let out of any tire. When the hose was connected to the tire, if the tire pressure was greater than the hose pressure, the valve would close and no air would be let out of the tire; but if the tire pressure was initially less than the hose pressure, the valve would open and allow air to flow from the hose into the tire until the tire pressure equalled the hose pressure. In this way tires that initially were inflated to a pressure greater than the hose pressure would not be affected, but tires that were initially inflated to a pressure lower than the hose pressure would be inflated up to the hose pressure.

The remaining question is how to choose this hose pressure. A higher hose pressure will give a higher resulting average tire inflation pressure, but it will also result in more tires being inflated to pressures greater than that recommended by the vehicle manufacturer. Higher average inflation pressure is desirable because it decreases tire energy dissipation and hence gives improved fuel economy. Increased inflation pressure also improves tire treadlife, with little apparent effect on traction. Drastic increases in inflation pressure should be avoided, however, since handling may be affected and impact bruise resistance may be lowered at very high inflation pressures.5/

Selecting the hose pressure clearly involves making a tradeoff between increasing fuel economy and increasing tire inflation pressure above the vehicle manufacture's recommended pressure. A computer program was used to predict how passenger car tire inflation pressure would be affected by choices of target cold inflation pressure from 22 to 32 psi. These data are shown in table 3.

Figure 3 is a plot of the average amount of tire pressure above the recommended pressure versus the percentage reduction in fuel economy. This figure clearly shows that increasing the hose pressure results in a reduction in fuel consumption but also results in a greater amount of inflation over the recommended pressure. The lower end of the curve is nearly flat which means that a hose pressure of up to 24 psi will result in reduced fuel consumption with very little increase in inflation over recommended pressures. Therefore there is no reason to choose a target cold inflation pressure less than 24 psi.

If a target cold inflation pressure of 24 psi were used the average inflation pressure would be increased to 26.0 psi while barely increasing the average amount of inflation over the recommended pressure from 0.98 to 1.0 psi. So a cold inflation pressure of 24 psi would barely increase overinflation but would still result in 0.52 percent reduction in fuel consumption which is a potential fuel savings of 27,000 bbl. per day.

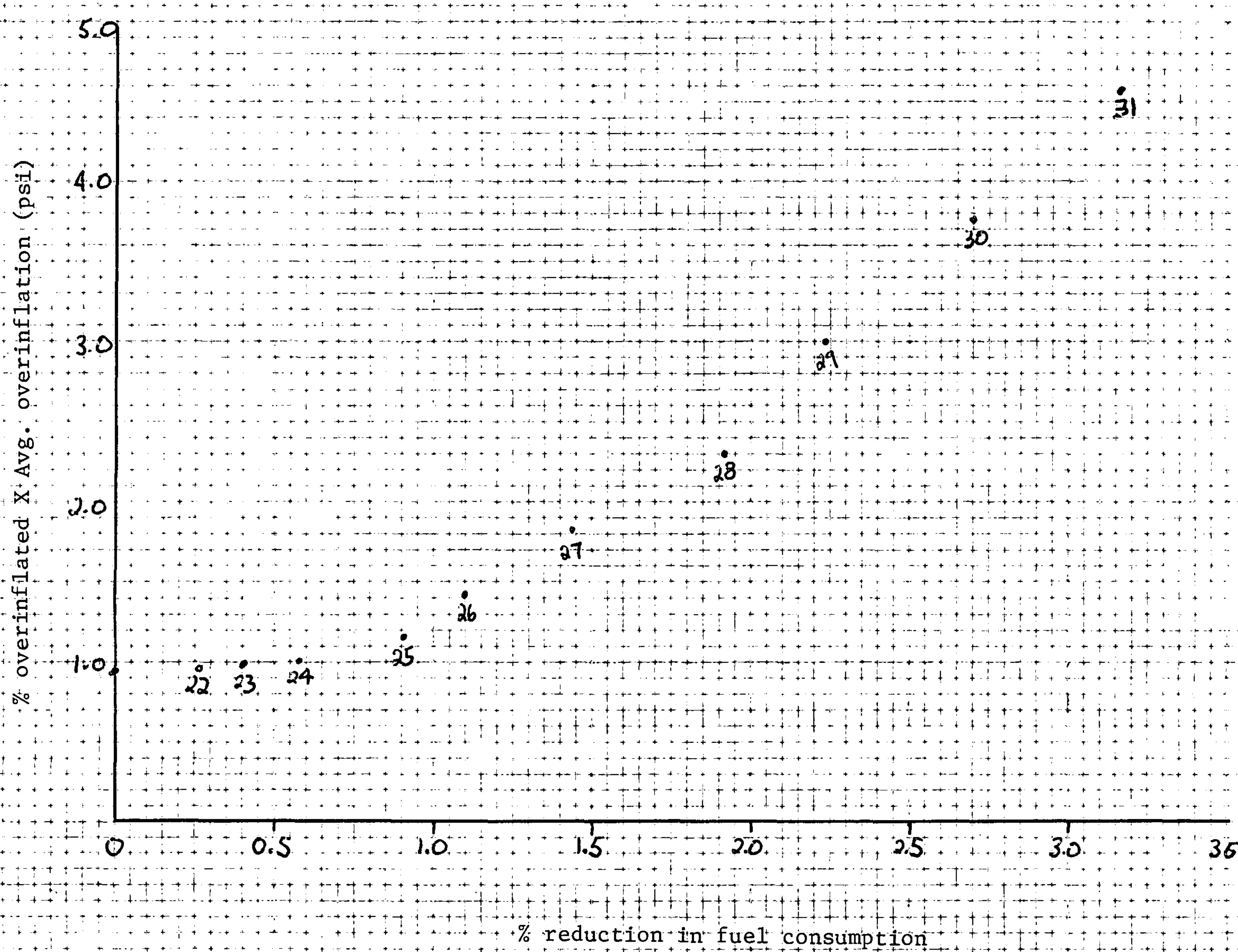
A more aggressive program could use a target cold inflation pressure of 28 psi. This would increase average inflation pressure to 28.4 psi while increasing the average amount of overinflation to 2.3 psi. This would reduce fuel consumption by 1.48 percent or 77,000 bbl. of fuel per day.

Table 3

		AVG	STD	%UNDER	AVG UNDER	%OVER	AVG OVER
22	FRONT	25.371	3.207	56.065	3.246	34.098	3.655
22	REAR	25.273	3.100	68.349	4.086	23.089	3.302
22	COMBINED	25.322	3.154	62.207	3.666	28.593	3.479
23	FRONT	25.635	2.950	55.861	2.799	34.709	3.612
23	REAR	25.541	2.838	68.298	3.700	23.242	3.292
23	COMBINED	25.588	2.894	62.080	3.250	28.976	3.452
24	FRONT	25.996	2.651	40.775	2.982	34.964	3.625
24	REAR	25.910	2.532	56.830	3.810	23.445	3.291
24	COMBINED	25.953	2.592	48.802	3.396	29.205	3.458
25	FRONT	26.466	2.324	39.908	2.384	53.670	2.745
25	REAR	26.383	2.203	56.116	3.284	37.717	2.447
25	COMBINED	26.425	2.264	48.012	2.834	45.693	2.596
26	FRONT	27.036	1.993	24.465	2.615	54.740	3.162
26	REAR	26.962	1.869	44.139	3.288	38.634	2.873
26	COMBINED	26.999	1.933	34.302	2.951	46.687	3.018
27	FRONT	27.708	1.673	23.394	1.904	73.293	3.014
27	REAR	27.641	1.551	43.680	2.580	52.905	2.769
27	COMBINED	27.675	1.614	33.537	2.242	63.099	2.891
28	FRONT	28.464	1.384	6.932	3.382	74.618	3.690
28	REAR	28.411	1.263	24.108	3.133	53.466	3.484
28	COMBINED	28.437	1.325	15.520	3.258	64.042	3.587
29	FRONT	29.294	1.134	6.830	2.657	92.915	3.800
29	REAR	29.258	1.014	23.649	2.338	75.433	3.325
29	COMBINED	29.276	1.076	15.240	2.498	84.174	3.562
30	FRONT	30.188	0.924	6.116	1.967	93.017	4.691
30	REAR	30.157	0.809	17.278	1.929	75.892	4.199
30	COMBINED	30.173	0.869	11.697	1.948	84.455	4.445
31	FRONT	31.116	0.756	6.116	1.000	93.833	5.576
31	REAR	31.097	0.646	16.667	1.000	82.416	4.805
31	COMBINED	31.107	0.703	11.391	1.000	88.124	5.191
32	FRONT	32.077	0.621	0.000	0.000	93.833	6.535
32	REAR	32.061	0.514	0.000	0.000	83.129	5.723
32	COMBINED	32.069	0.570	0.000	0.000	88.481	6.129

Figure 3

Overinflation vs Reduction in Fuel Consumption
for Indicated Target Inflation Pressures



The most aggressive program would be to use a target cold inflation pressure of 32 psi. This would raise the average inflation pressure to 32.1 psi while increasing the average amount of inflation above the recommended pressure to 5.4 psi. This pressure, 32 psi, is in general the maximum inflation pressure recommended for current tires by tire manufacturers and should certainly be considered a safe pressure. At 32 psi no tire overinflation would occur that would cause direct tire safety problems. It is possible, however, that a target cold inflation pressure of 32 psi could cause adverse handling effects on those vehicles with major differences in recommended front and rear pressures such as older Volkswagen sedans (Beetles).

Tire inflation pressures of up to 4 psi above the vehicle manufacturer's recommended pressure should generally be acceptable resulting in no signigicant change in vehicle handling or degradation in the vehicle ride. As shown in table 4, if 24 psi were chosen as the target pressure only 0.03 percent of all tires would be increased to a pressure more than 4 psi above the vehicle manufacturer's recommended pressure. If 28 psi were the target pressure, only about 2 percent of all tires would be inflated to a pressure more than 4 psi above their recommended pressure. The number of tires inflated to more than 4 psi above their recommended pressures does increase dramatically for target pressures above 28 psi. For a cold target inflation pressure of 32 psi, more than 57 percent of all tires would be inflated to a pressure more than 4 psi above the vehicle manufacturer's recommended pressure. This dramatic increase is due to the fact that many tires have a recommended pressure of 24 psi. This can be seen in figures 4 and 5 which are histograms of recommended front and rear tire inflation pressures. These figures show that the most common recommended inflation pressures are 24 psi and 26 psi so that even with a hose pressure of 28 psi most tires will be inflated above their recommended pressure by only 2 or 4 psi. Thus a hose pressure of 28 psi gives a generally acceptable inflation pressure while yielding a significant reduction in fuel consumption.

It should be noted that all pressures discussed thus far are cold tire inflation presures. In an actual vehicle inspection lane program, vehicles will be checked with the tires warmed up to varying degrees. As tires warm up their inflation pressures will increase by about 4 psi after 45 minutes of operation. On the average a tire passing the inspection lane will be partially warmed-up, therefore the hose pressure used should be increased by about 2 psi over the desired cold inflation pressure to account for this condition. However, some vehicles passing through the lane will have cold tires so no hose pressure greater than 32 psi should be used.

It should be noted that this report only considered fuel savings from increasing the pressure in passenger car tires. If light-duty trucks were included in this program addtional fuel savings would result; however, the pressures discussed in this report are not appropriate for light-duty trucks.

Table 4

Target Cold Inflation Pressure Psi	Avg. Inflation	% inflated by more than 4 psi over recommended	% Fuel Savings	Fuel Savings bbl/Day
24	26.0	0.03	0.52	27,000
26	27.0	0.25	0.92	48,000
28	28.4	2.06	1.48	77,000
30	30.2	31.91	2.20	114,000
32	32.1	57.39	2.96	154,000

```
HISTOGRAM

MIDPOINT     COUNT FOR 1.FSPEC   (EACH X= 19)

 18.000        0 +
 19.000        0 +
 20.000        4 +X
 21.000        5 +X
 22.000       53 +XXX
 23.000       12 +X
 24.000      723 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 25.000       35 +XX
 26.000      527 +XXXXXXXXXXXXXXXXXXXXXXXXXXXX
 27.000       32 +XX
 28.000      428 +XXXXXXXXXXXXXXXXXXXXXXX
 29.000        2 +X
 30.000       19 +X
 31.000        0 +
 32.000      121 +XXXXXXX
```

Figure 4

Distribution of Recommended Front Tire Inflation Pressures

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HISTOGRAM

MIDPOINT     COUNT FOR 2.RSPEC   (EACH X= 13)

 18.000        1 +X
 19.000        0 +
 20.000        4 +X
 21.000        1 +X
 22.000       10 +X
 23.000        9 +X
 24.000      503 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 25.000       23 +XX
 26.000      390 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 27.000       12 +X
 28.000      506 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 29.000        9 +X
 30.000      139 +XXXXXXXXXXX
 31.000       15 +XX
 32.000      339 +XXXXXXXXXXXXXXXXXXXXXXXXXXX
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Figure 5

Distribution of Recommended Rear Tire Inflation Pressures

Conclusion

Analysis of data collected during the emission factors program from in-use vehicles show that the average passenger car tire is underinflated by 1.8 psi. Because underinflated tires have higher energy dissipation, their presence in the passenger car fleet causes fuel consumption to be higher than necessary. A program to add air to underinflated tires could result in a fuel savings of 0.5 to 3 percent.

A simple method to increase inflation pressure suitable for use in a vehicle inspection lane would be to use a pressure hose maintained at a constant pressure to inflate tires. A check valve would be used on the pressure hose to insure that air is never let out of tires. A program using this method would produce the following results for the indicated target cold inflation pressures.

Target Cold Inflation Pressure	Resulting Avg. Pressure	% Reduction in Fuel Consumption	Fuel Savings bbl/day
24	26.0	0.52	27,000
28	28.4	1.48	77,000
32	32.1	2.96	154,000

Since vehicles arriving in an inspection lane will have tires that are warmed-up to varying degrees, 2 or 3 psi should be added to the desired cold inflation pressure to account for this warm-up effect.

Recommendations

A hose pressure of 30 psi is recommended for any inflation lane programs. This hose pressure would result in an average cold inflation pressure of about 28 psi. This is considered to be an acceptable pressure since:

a) No tire would be inflated above the tire manufacturer's recommended maximum inflation pressure of 32 psi.

b) Only about 2 percent of all tires would be inflated by more than 4 psi above the vehicle manufacturer's recommended pressure.

c) Few vehicles would experience significant ride changes, therefore, few complaints from the public would be expected.

d) In general it is not expected that vehicle handling would be significantly affected; however, a few vehicles with large differences in recommended front and rear tire inflation pressures might experience some changes in handling. Perhaps these few vehicles should be excluded from the program.

References

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