IN-SERVICE EVALUATION OF NITROGEN INFLATION OF TIRES

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Abstract

The use of nitrogen gas inflation for tires in severe service conditions is known. A variety of benefits have been claimed for use in passenger car tires. In order to study specific claims, the use of dry air and dry pure nitrogen inflation was tested in both laboratory testing and evaluations under in-service conditions.

It is shown from laboratory experiments that the primary benefit of using nitrogen as the filling gas is to reduce the tire inflation pressure retention (Tire IPR) monthly loss rate values. Other claimed benefits such as cooler operating temperature and lower rolling resistance are found to be the primary result of tire inflation pressure, with the type of filling gas being statistically insignificant.

An in-service evaluation of four tire types on different vehicles also shows that the benefit of nitrogen gas inflation is to reduce the actual Tire IPR loss rates measured on the vehicle. A small measurable benefit is observed for vehicle fuel economy, but is a primary effect of inflation pressure with inflation gas again being statistically insignificant.

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Agenda

- Background
- Tire Inflation Pressure Retention
- Vehicle Fuel Economy
- Statistical Analysis
- Summary

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Background: Reported Benefits of Nitrogen

Bowen Independent

(Ref: Bowen Independent (Australia), March 7, 2007, Pg. 17)

- "Nitrogen molecules are four times larger than air and as a result will not seep through the casing of the tyre like air...".
- "As normal compressed air passes through the casing of the tyre, oxidation is caused within the tyre belts, reducing the life of the casing and increasing the risk of blow outs".
- "Fluctuation in pressure means increased temperature resulting in increased tyre wear. As the pressure in the tyre is more constant, you will not get the increase in temperature and pressure like you get with tyres inflated with normal compressed air".

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Background: Reported Benefits of Nitrogen

Times & Transcript

(Ref: Times & Transcript (New Brunswick), February 11, 2008)

- **"... nitrogen is a dry gas that is free of moisture, unlike oxygen. The moisture in oxygen can, over the course of a tire's lifetime, break it down."**
- **"...increased tire life, better fuel economy, less chance of tire failure and better braking and handling, which makes for a safer drive.**
- **"Also, if it extends the life of a tire, that's less waste that could make its way back into the environment."**

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Agenda

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  - **Laboratory Studies**
  - **In-Service Study**
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Gas Diffusion in Rubber

- **Nitrogen (0.10977nm) molecule is similar size to oxygen (0.12074nm)**
  (Ref: Handbook of Chemistry and Physics, 78th Edition, The Chemical Rubber Co., New York, 1997)
- **Nitrogen is 50% less soluble in natural rubber than is oxygen gas**
  (Ref: van Amerongen, "Diffusion in Elastomers", Rubber Reviews, 37, 1065 (1964))
- **Nitrogen gas calculated to be 30% - 40% less permeable in rubber than oxygen gas**
  - Natural Rubber @25°C $N_2 = 6.12$ $O_2 = 17.7$ ($10^{-8}cm^2.sec^{-1}.atm^{-1}$)
    - For Natural Rubber $Q_{Air} \sim 1.4\ Q_{Nitrogen}$ → *70%* of Air Value
  - Butyl Rubber @25°C $N_2 = 0.247$ $O_2 = 0.99$
    - For Butyl Rubber $Q_{Air} \sim 1.63\ Q_{Nitrogen}$ → *60%* of Air Value

Nitrogen Less Soluble → Less Permeable than Oxygen

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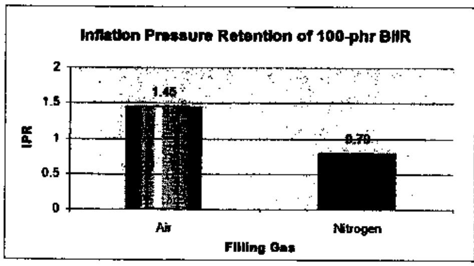
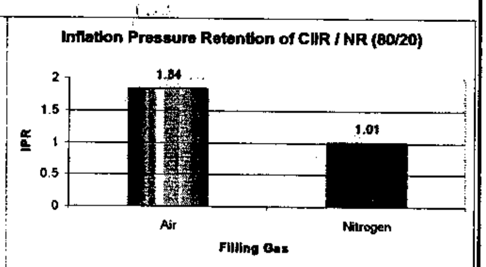
Filling Gas Effects: Tire IPR

Used ASTM F-1112 (modified) to study Inflation Pressure Retention loss rates of P205/60 SR15 tires with different innerliners

- Tires purged 3X in order to obtain pure gas: dry 99.4% nitrogen





IPR %-Loss/Month Rates Reduced 45% Using Dry, Pure Nitrogen Gas Inflation

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Filling Gas Effects: Tire IPR

Consumer Reports
(Ref: Petersen, "Consumer Reports Tire Testing. A Consumers Perspective", ITEC 2008, Akron, OH, 9/16-18/2008)

- **Studied 31 H- and V-rated, all-season tires**
  - Filled with nitrogen / deflated 3X to purge air out of tire
  - Oxygen analyzer used to ensure 95% nitrogen purity
  - One-year test showed nitrogen reduces pressure loss over time. From initial 30 psi, 3.5 psi air pressure loss, while nitrogen-filled tires lost an average of 2.2 psi: **37%** lower for tires inflated with nitrogen gas

National Highway Traffic Safety Administration
(Ref: MacIsaac, Evans, Harris, Terrill, "The Effects of Inflation Gas on Tire Laboratory Performance", ITEC 2008, 9/16-18/08)

- **Studied nitrogen (94 to 99%) inflation of 25 passenger or LT tires**
  - **34%** lower IPR loss rates for tires inflated with nitrogen gas
  - Tire type also a statistically significant variable

In Agreement with Consumer Reports and NHTSA Results:
IPR Loss Rates Reduced ~35% Using Nitrogen Inflation

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  - **In-Service Study**
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- **Summary**

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In-Service Study: Equipment

- **New tires were tested on four vehicles driven under normal city driving conditions using dry air or dry 99+% nitrogen gas inflation from purchased cylinders**
  - Tires were purged and refilled three times in order to obtain pure dry nitrogen gas inflation (**99+%**)

Vehicle	1	2	3	4
Type	Luxury PassengerCar	Small Light Truck	Full-size Passenger Car	Small SUV
Year	1998	1998	2000	2007
Engine	8 cylinders	4 cylinders	4 cylinders	4 cylinders
Transmission	Automatic	Manual	Automatic	Automatic
Tire	A	B	C	D
Type	All Season M+S	All Season M+S	All Season M+S	All Season M+S
Size	P215/60R16 94V	P215/65R15 95H	P205/60R15 91H	P215/70R16 99H
IPR*	1.4	2.2	2.3	2.5

* = ASTM F1112-06

SIDE STUDY OVER 2 YEARS.

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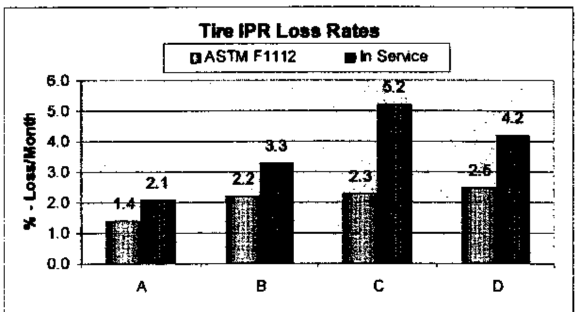
Tire IPR Loss Rates: Air Inflation

- **Tire Inflation Pressure Retention loss rates (%-month) dependent upon tire type and measurement type**
  - ASTM F1112-06 measured at 21°C for unloaded, static tire
  - In-service IPR measured at ambient temperatures for tires on vehicles



LOSS RATES FOR AIR IN SVC + RIGHT 3 = DRAMATICALLY HIGHER.

Tire IPR Loss Rates Increased Significantly
<u>When Measured In-Service</u>

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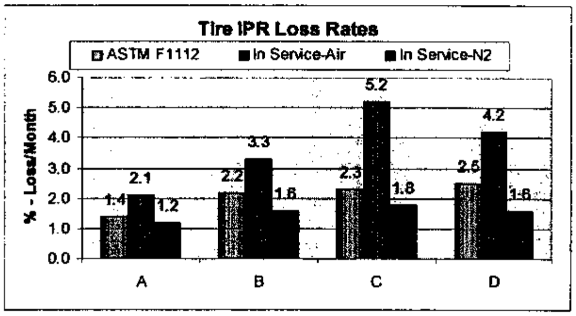
In-Service Study: Tire IPR

- **Inflation pressure was measured directly for each tire on the vehicle, and the average value for all four tires was used to calculate Tire IPR monthly loss rates based on 10 weeks of data**
  - Air inflated, Nitrogen gas inflated, Air inflated and Nitrogen gas inflated



IPR Loss Rates Lower for Nitrogen Inflated Tires

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LOSS RATES FOR N2 (RIGHT BAR) ARE SIGNIFICANTLY BETTER THAN AIR.
COMMENT BY CHEV NAPIER!
N2 DID BETTER ON TIRE WITH WORST IN-SVC IPR.
NOT MUCH BENEFIT ON GOOD IPR (TIRE A)

Agenda

- **Background**
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- **Vehicle Fuel Economy**
  - **Laboratory Rolling Resistance**
  - **In-Service Evaluation**
- **Statistical Analysis**
- **Summary**

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Tire Rolling Resistance Characterization

- **Rolling resistance measured at Smithers Scientific Services on 1.708-m indoor roadwheel at 24°C**
  - P205/60 SR15, 100-phr BIIR innerliner with cured gauge of 1.0 mm
  - Six inflation pressures requested: 32, 31, 30, 28, 26, 24 psi
- **Single Point Inflation**
  - Measured at 50 mph, 70% load and one inflation pressure
  - Tire Footprints obtained and areas determined
- **SAE J1269**
  - Current recommended practice used to evaluate tires by tire industry
  - Measured at constant 50 mph speed at 50% and 90% of maximum load and two inflation pressures
- **SAE J2452**
  - Current recommended practice used to evaluate tires and effect on vehicle fuel economy
  - Many OEM's use this technique to generate CAFE predictions
  - Measured at speed of 71 mph coasting down to 9 mph at two loads and two inflation pressures; rolling resistance values calculated

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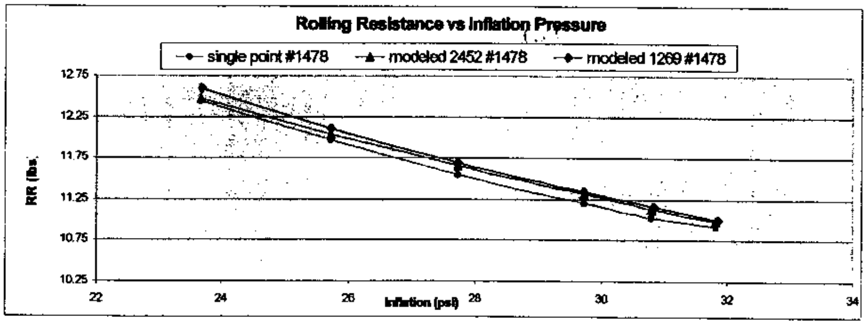
Rolling Resistance Characterization: Tests

- **Three tests run: Single-point inflation, SAE J1269 and SAE J2452**
  - Tests on experimental tires: P205/60 SR15, 1-mm, 100-phr BIIR

Test Methods Comparison



- **Rolling resistance (RR) measured experimentally**
  - Excellent reproducibility between 3 methods: Mean = 10.754, SD = 0.045

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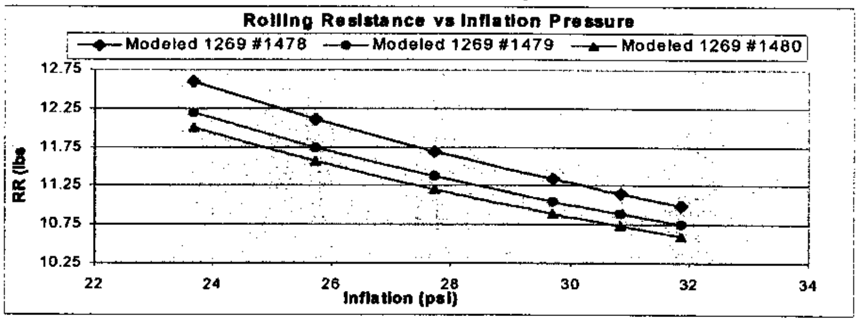
Rolling Resistance Characterization: Tires

- **Three tests run: Single-point inflation, SAE J1269 and SAE J2452**
  - Tests on experimental tires: P205/60 SR15, 1-mm, 100-phr BIIR

Tire Reproducibility



- **Rolling resistance (RR) measured experimentally**
  - Excellent reproducibility between 3 tires: Mean = 10.754, SD = 0.20

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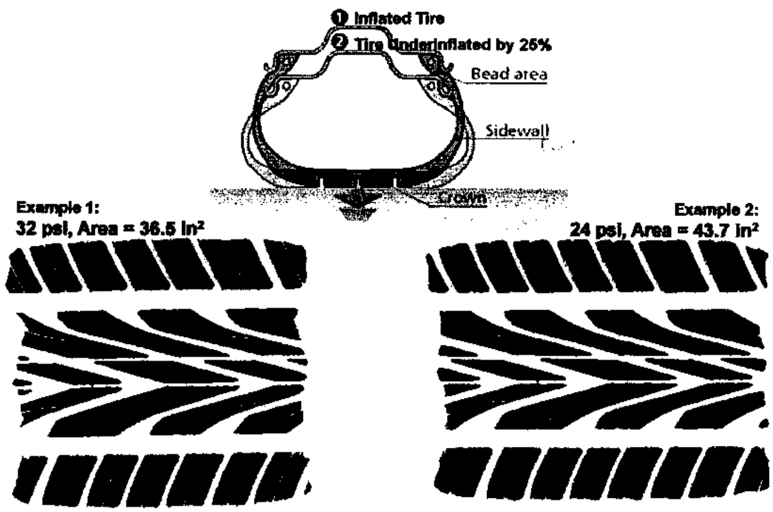
Tire Inflation Pressure Effects: Footprint



25% Pressure Loss Increases Footprint 20%

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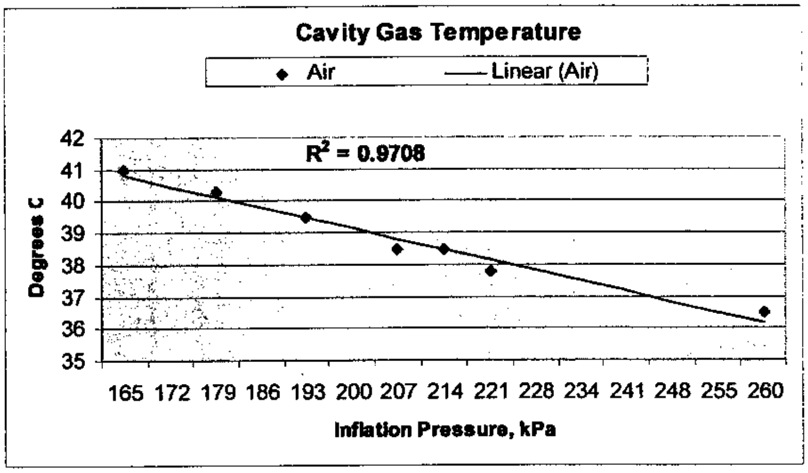
Filling Gas Effects: Cavity Gas Temperature



Cavity Air Temperature Dependent Upon Inflation Pressure

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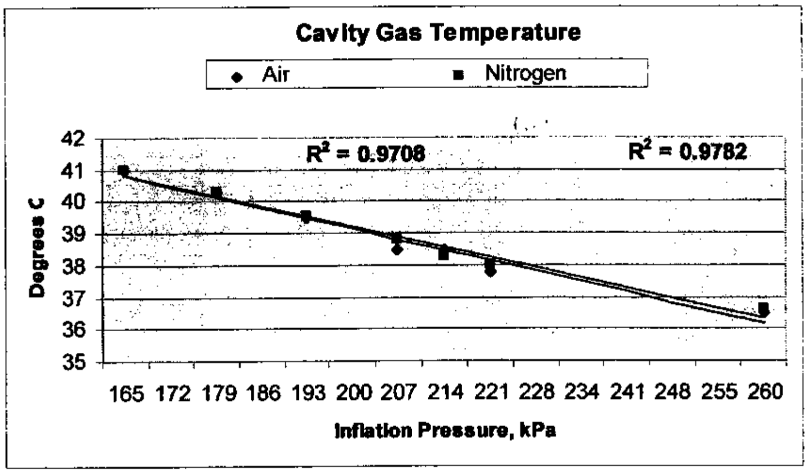
Filling Gas Effects: Cavity Gas Temperature



Cavity Air Temperature Does Not Change using Nitrogen Gas

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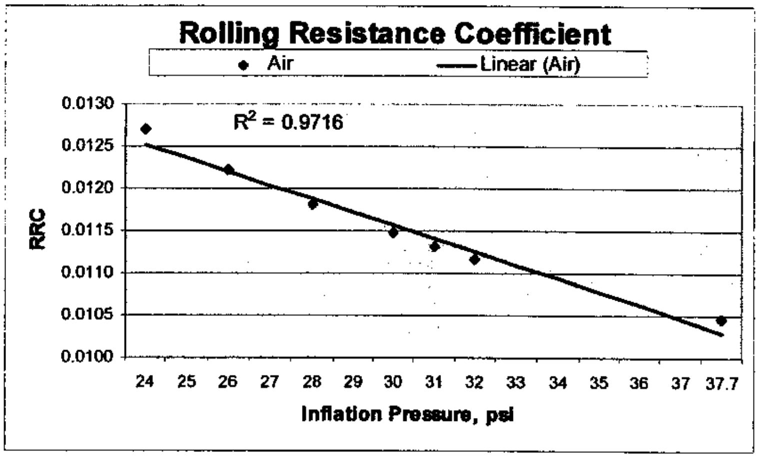
Filling Gas Effects: Tire Rolling Resistance



Tire Rolling Resistance Dependent Upon Inflation Pressure

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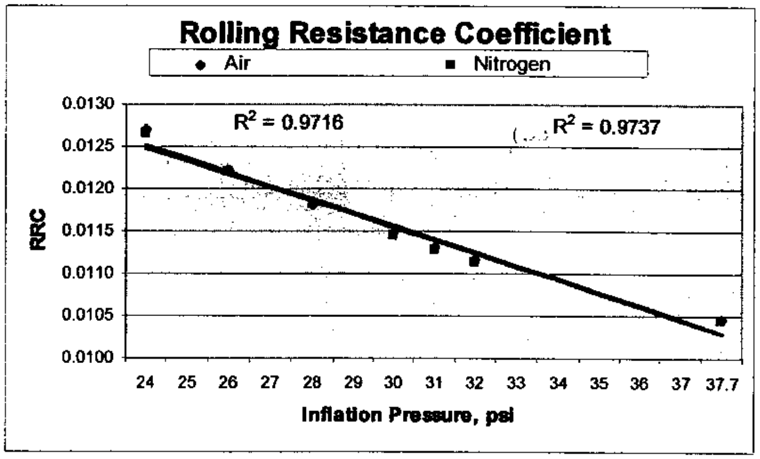
Filling Gas Effects: Tire Rolling Resistance



Tire Rolling Resistance Does Not Change Using Nitrogen

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Filling Gas Effects: Tire Rolling Resistance

National Highway Traffic Safety Administration
(Ref: MacIsaac, Evans, Harris, and Terrill, "The Effects of Inflation Gas on Tire Laboratory Performance", ITEC 2008, 9/16-18/08)

- **Studied rolling resistance of 24 tire types and ASTM F09 SRT**
- **SAE J1269 test procedure**
- **Filling with nitrogen gas or air inflation gave essentially identical results**

RR_{Air}	12.80+/-0.38 lbs
RR_{N2}	12.65+/-0.44 lbs

In Agreement with NHTSA Results:
Tire Rolling Resistance Equivalent Using Nitrogen Gas

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Agenda

- **Background**
- **Tire Inflation Pressure Retention**
- **Vehicle Fuel Economy**
  - **Laboratory Rolling Resistance**
  - **In-Service Evaluation**
- **Statistical Analysis**
- **Summary**

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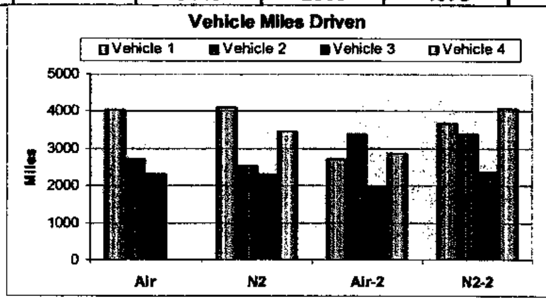
In-Service Study: Miles Driven

- **Vehicle miles driven under normal city/highway conditions**
  - Gallons of gas consumed recorded for each fill-up during the four 10-week time periods: 45,961 total miles driven

Vehicle	Miles Driven				
	Air	N2	Air-2	N2-2	Total
1	4030	4115	2720	3677	14543
2	2726	2537	3388	3381	12032
3	2328	2317	1984	2371	9000
4		3449	2860	4078	10387



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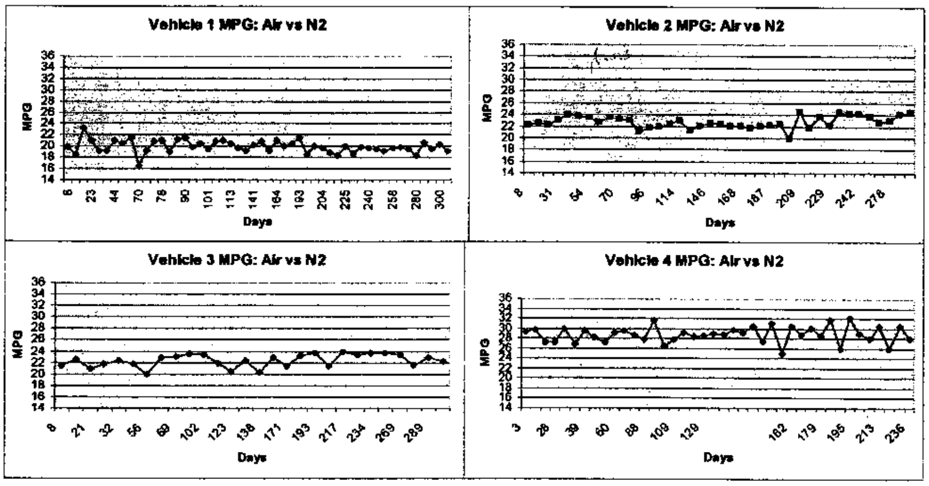
In-Service Study: Gasoline Consumed

- **Average miles per gallon was obtained under normal city driving conditions in order to determine the effect of nitrogen inflation on vehicle fuel economy**



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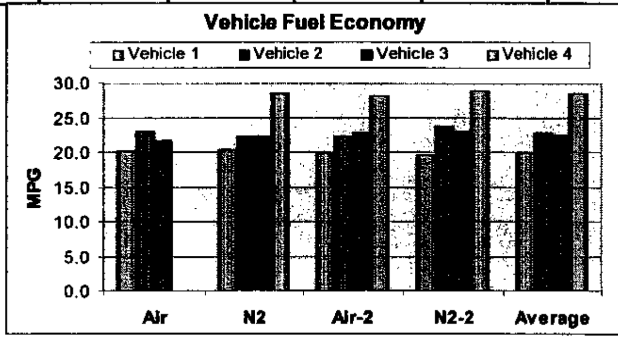
In-Service Study: Gasoline Consumed

- Average miles per gallon was obtained in order to determine the effect of nitrogen inflation on vehicle fuel economy

Vehicle	MPG				
	Air	N2	Air-2	N2-2	Average
1	20.1	20.3	19.9	19.6	20.0
2	23.1	22.2	22.2	23.7	22.8
3	21.7	22.2	22.8	23.0	22.4
4		28.5	28.1	28.9	28.5



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Agenda

- Background
- Tire Inflation Pressure Retention
- Vehicle Fuel Economy
- **Statistical Analysis**
  - All Vehicles
  - Independent Vehicle Analysis
- Summary

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Statistical Analysis

- **SAS JMP software used to statistically analyze data**
  1. **Fuel economy analyzed collectively using all vehicle and tire and data**
  2. **Fuel economy analyzed independently for each vehicle**
- **Similar results obtained using either approach**

Nitrogen Inflation of Tires Gives
Statistically Identical Vehicle Fuel Economy

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Gas Mileage Effects: Tire Type

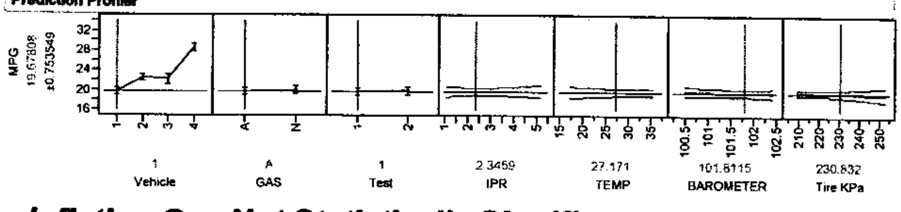
Scaled Estimates

Nominal factors expanded to all levels
Continuous factors centered by mean, scaled by range/2

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	23.476592	0.117268	200.20	<.0001*
Vehicle[1]	-3.563654	0.30291	-11.76	<.0001*
Vehicle[2]	-0.723551	0.204661	-3.54	0.0005*
Vehicle[3]	-1.108091	0.282286	-3.93	0.0001*
Vehicle[4]	5.3952963	0.195129	27.65	<.0001*
GAS[A]	-0.163009	0.270548	-0.60	0.5478
GAS[N]	0.1630093	0.270548	0.60	0.5478
Test[1]	-0.071843	0.106705	-0.67	0.5018
Test[2]	0.071843	0.106705	0.67	0.5018
IPR	0.0844243	0.452126	0.19	0.8521
TEMP	0.0303879	0.258682	0.12	0.9066
BAROMETER	-0.169403	0.321029	-0.53	0.5985
Tire KPa	-0.191698	0.381145	-0.50	0.6157

Vehicle Type is Only Statistically Significant Variable, Prob>|t|<0.1

Prediction Profiler



Inflation Gas Not Statistically Significant: Prob>|t|=0.9

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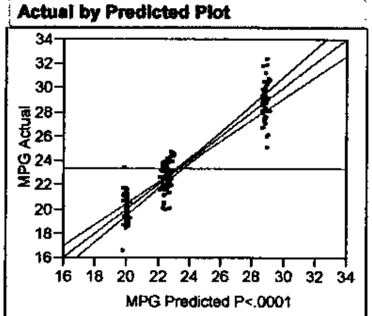
Gas Mileage Effects: Tire Type

Response MPG

Actual by Predicted Plot



Summary of Fit

RSquare	0.879701
RSquare Adj	0.872336
Root Mean Square Error	1.297404
Mean of Response	23.36962
Observations (or Sum Wgts)	157

Good Qualitative Model of All Data:

<u>R^2 = 0.88</u>

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Gas Mileage Effects: Inflation Pressure and IPR

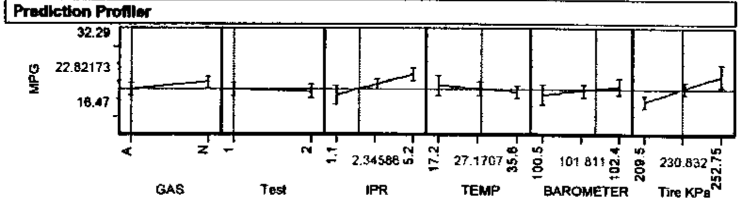
Scaled Estimates

Nominal factors expanded to all levels

Continuous factors centered by mean, scaled by range/2

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	23.272876	0.264082	88.13	<.0001
GAS[A]	-0.719682	0.559837	-1.29	0.2006
GAS[N]	0.7196821	0.559837	1.29	0.2006
Test[1]	0.2685351	0.261499	1.03	0.3061
Test[2]	-0.268535	0.261499	-1.03	0.3061
IPR	2.3090921	0.760493	3.04	0.0028 ←
TEMP	-0.712766	0.582897	-1.22	0.2233
BAROMETER	0.9040906	0.784105	1.15	0.2507
Tire KPa	2.8965046	0.733452	3.95	0.0001 ←

Prediction Profiler



Tire Inflation Pressure and Tire IPR are
<u>Statistically Next Most Important Variables</u>

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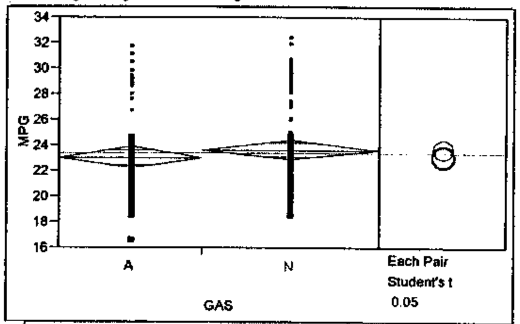
Gas Mileage Effects: Air vs N_2 Inflation

Oneway Analysis of MPG By GAS



Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%	
A	70	23.0244	0.43380	22.167	23.881	
N	87	23.6474	0.38912	22.879	24.416	**2.7% Difference**

Std Error uses a pooled estimate of error variance

Small, But Not Statistically Significant, Difference in <u>Vehicle Fuel Economy Using Air or Nitrogen</u>

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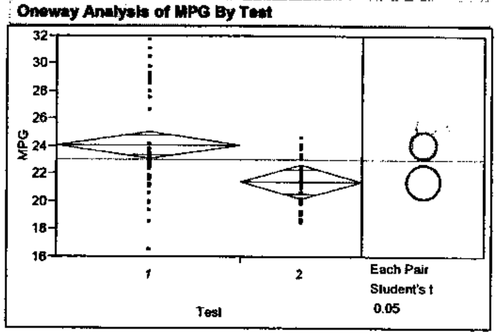
Temperature Effects: Air-1 vs Air-2

Oneway Analysis of MPG By Test



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Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%	
1	42	24.0929	0.49136	23.112	25.073	
2	28	21.4218	0.60179	20.221	22.623	**11.1% Decrease**

Std Error uses a pooled estimate of error variance

Temperature Effect of Using Air Conditioner in <u>Summer Months during Air-2 Measurements</u>

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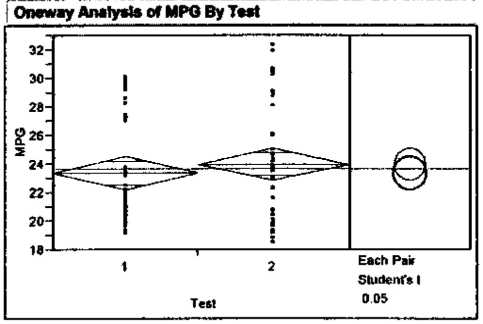
Temperature Effects: N_2-1 vs N_2-2

Oneway Analysis of MPG By Test



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Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	42	23.3186	0.58545	22.155	24.483
2	45	23.9542	0.56560	22.830	25.079

Std Error uses a pooled estimate of error variance

2.7% Difference

Temperature Effect of Using Air Conditioner in Summer Months during Nitrogen-1 Measurements

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- **Statistical Analysis**
  - **All Vehicles**
  - **Independent Vehicle Analysis**
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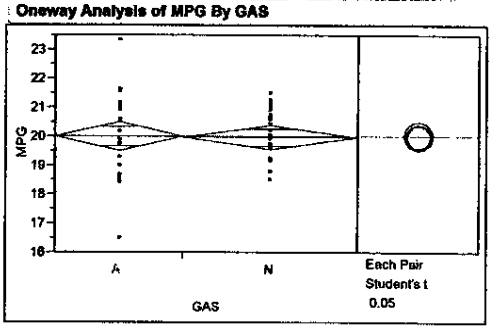
Filling Gas Effects: Air vs N_2

Vehicle 1

Oneway Analysis of MPG By GAS



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Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
A	21	20.0024	0.24384	19.513	20.492
N	29	19.9690	0.20733	19.552	20.386

Std Error uses a pooled estimate of error variance

0.15% Decrease

No Statistical Difference Using Air or Nitrogen to Fill Tires

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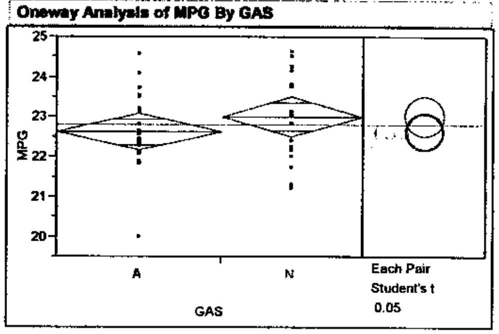
Filling Gas Effects: Air vs N_2

Vehicle 2

Oneway Analysis of MPG By GAS



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Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
A	21	22.6081	0.22610	22.150	23.066
N	18	22.9978	0.24421	22.503	23.493

Std Error uses a pooled estimate of error variance

1.7% Increase

No Statistical Difference Using Air or Nitrogen to Fill Tires

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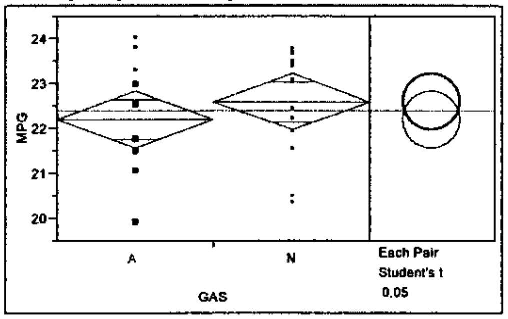
Filling Gas Effects: Air vs N_2

Vehicle 3

Oneway Analysis of MPG By GAS



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Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
A	14	22.1993	0.30766	21.567	22.832
N	14	22.5914	0.30766	21.959	23.224

1.7% Increase

Std Error uses a pooled estimate of error variance

No Statistical Difference Using Air or Nitrogen to Fill Tires

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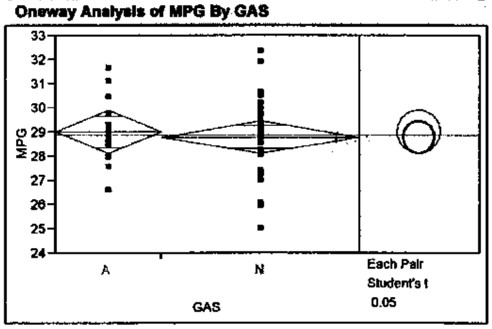
Filling Gas Effects: Air vs N_2

Vehicle 4

Oneway Analysis of MPG By GAS



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Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
A	14	29.0071	0.44274	28.111	29.903
N	26	28.7685	0.32489	28.111	29.426

0.8% Decrease

Std Error uses a pooled estimate of error variance

No Statistical Difference Using Air or Nitrogen to Fill Tires

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Summary

- **Tire IPR loss rates measured in-service much greater than measured using ASTM F1112 test protocol**
  - 50% to 125% increases in monthly loss rates
- **Use of dry 99+% nitrogen to inflate tires for in-service testing on vehicles shows 40% to 65% reduced Tire IPR loss rates**
- **Tire type is only statistically significant variable using Prob>|t|<0.1**
  - Inflation gas type is not statistically significant: Prob>|t|=0.9
- **No statistical difference in fuel economy using air or nitrogen to inflate tires during 46,000-mile in-service four vehicle study**
- **Effect of ambient temperature observed on vehicle fuel economy since measured mpg lowest in summer months**
  - Up to 11% decrease in vehicle mpg when air-conditioning is turned on during summer months

In-Service Evaluation of Nitrogen Inflation of Tires

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