[redacted] and [redacted]
MATH 216
Application Project
April 24, 2007

Testing for Boost Leaks in a Turbocharged Engine

Background

A turbocharger is a device used in internal combustion engines to improve engine performance by forcing compressed air into the combustion chambers. This increase in available oxygen allows more fuel to be burned in a shorter amount of time and thus results in a larger power output. One of the defining characteristics of a turbocharged engine is its boost, which is the increase in pressure in the intake manifold as a result of the forced induction of the turbocharger. As the boost level increases, more air is forced into the combustion chambers, and, consequently, more power is produced by the engine. A turbocharged engine relies on a series of sealed valves and tubes to deliver the compressed air from the turbocharger to the combustion chambers. Therefore, if there is a leak in the system, some of the air will escape before it reaches the combustion chambers, resulting in decreased levels of boost and less power output.

An example of a car that has a turbocharged engine is an Audi S4. Using a computer-controlled automotive diagnostic tool called a VAG-COM, one can measure and log various engine parameters of this car in real-time. The VAG-COM cable connects to the S4's diagnostic port on one end and to the serial port of a computer on the other end. The VAG-COM software on the computer allows the user to control which engine parameters are measured. In particular, the user can log the boost level that the car's electronic control unit is requesting based on the current position of the throttle, and then at the same time also log the boost level that the turbocharger is actually producing based on that request. These values are measured and recorded onto the computer by the VAG-COM software several times per second.

Problem

The owner[1] of an Audi S4 recently began to suspect that his car was not producing as much power as it should be. Since a boost leak would cause the power output of the engine to decrease, he decided to use his VAG-COM diagnostic tool in conjunction with his laptop computer to check for a boost leak by logging some engine data and then analyzing that data. At some point in the midst of a late night joyride, he began logging both the boost levels requested by the engine control unit and the boost levels actually produced by the turbocharger. After scanning the horizon for any lurking police cars, he proceeded to accelerate at wide open throttle from 2500 RPM in 3rd gear all the way to redline. In order to determine whether his car has a boost leak, he will conduct a paired *t*-test using the data he logged. He will first find the difference between the requested boost level and the actual boost level for each point in time. The null hypothesis will then be that the mean of the differences between the requested and actual boost levels will be zero. The alternative hypothesis will be that the mean of the differences between the requested and actual boost levels is greater than zero, indicating that the requested boost level was on average higher than the actual boost level. In performing this hypothesis test, the owner is assuming that the mean of the differences between the requested and actual boost levels follows a t-distribution. He will test this assumption by plotting the

[1] The owner is [redacted]

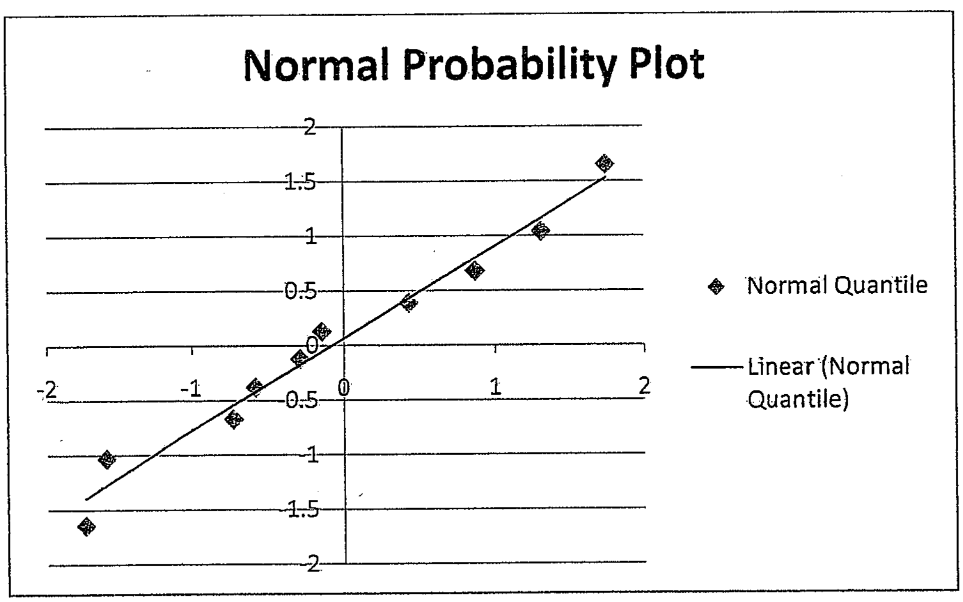
differences on a stem-and-leaf display and checking that the data are single-peaked, symmetric, and have tails that die rapidly. He will also construct a normal probability plot of the differences and check that the data points form a fairly straight line.

Calculations

Stem and Leaf Display

Stem	Leaves
-1.	75
-0.	7521
0.	48
1.	37

explanations?



Hypothesis Test

$$H_0: \delta = 0$$

$$H_a: \delta > 0$$

$$\alpha = 0.01$$

We reject the null hypothesis if $t > t_{9,0.01}$.

$$\bar{d} = -0.0725$$

$$s_d = 1.252$$

$$n = 10$$

$$t = \frac{-0.0725}{\frac{1.252}{\sqrt{10}}} = -0.169$$

$$t_{9,0.01} = 2.822$$

$-0.169 < 2.822$, so we are unable to reject the null hypothesis.

99% Confidence Interval

$$t_{9,0.005} = 3.250$$

$$-0.0725 \pm 3.250\frac{1.252}{\sqrt{10}} = (-1.359, 1.214)$$

Analysis

After conducting the hypothesis test using a significance level of 0.01, the car owner is unable to reject the null hypothesis. Therefore, it seems as though the owner's fear of a boost leak is unwarranted. In order to conduct this hypothesis test, the owner assumed that the differences between requested and actual boost levels followed a t-distribution. The owner checked this assumption using both a stem-and-leaf display and a normal probability plot. The stem-and-leaf display is single-peaked, symmetric, and has tails that die rapidly, so he should be fairly comfortable that the data come from a well-behaved distribution. The normal probability plot follows a fairly straight line, again indicating that the data come from a well-behaved distribution. The owner also constructed a 99% confidence interval. The interval is centered around zero, thus yielding further evidence that the true mean value of the actual boost levels is not different than the true mean value of the requested boost levels.

Works Cited

Turbocharger . (2007, April 20). Retrieved April 21, 2007, from Wikipedia: http://en.wikipedia.org/w/index.php?title=Turbocharger&oldid=125464301

Vag-Com Data Logging FAQ. (2005, April 04). Retrieved April 23, 2007, from Audiworld: http://forums.audiworld.com/a4/msgs/2300223.phtml

How used?

Time	RPM	Requested Boost (mbar)	Actual Boost (mbar)	Requested Boost (psi)
512.97	4080	2010	2050	14.79384928
513.29	4800	2080	2050	15.80911344
513.63	5520	2020	1900	14.93888701
514	6240	1920	1830	13.48850963
514.39	6760	1810	1820	11.89309452
514.73	5480	1970	1910	14.21369832
515.06	4600	2030	2050	15.08392475
515.39	4640	1120	1240	1.885490594
515.7	4400	990	1100	0
516	3640	990	1040	0

Actual Boost (psi)	Differences	Sorted Differences	P_i	Normal Quantile
15.37400023	-0.580150952	-1.740452856	0.05	-1.64
15.37400023	0.435113214	-1.595415118	0.15	-1.03
13.19843416	1.740452856	-0.72518869	0.25	-0.67
12.18316999	1.305339642	-0.580150952	0.35	-0.38
12.03813225	-0.145037738	-0.290075476	0.45	-0.12
13.3434719	0.870226428	-0.145037738	0.55	0.13
15.37400023	-0.290075476	0.435113214	0.65	0.39
3.62594345	-1.740452856	0.870226428	0.75	0.68
1.595415118	-1.595415118	1.305339642	0.85	1.04
0.72518869	-0.72518869	1.740452856	0.95	1.65

d_bar

-0.072518869

s_d

1.352143827

t

-0.169600892