



From: Gerry Cole
 Seagate Personal Storage Group
 Longmont, Colorado
 Date: November 2000
 Number: TP-338.1



Estimating Drive Reliability in Desktop Computers and Consumer Electronics Systems

Introduction

Historically, desktop computers have been the primary application for hard disc storage devices. However, the market for disc drives in consumer electronic devices is growing rapidly. This paper presents a method for estimating drive reliability in desktop computers and consumer electronics devices using the results of Seagate's standard laboratory tests. It provides a link between Seagate's published reliability specifications and *real-world* drive reliability as experienced by the end-user.

Definitions

Seagate estimates the mean time between failures (MTBF) for a drive as the number of power-on hours (POH) per year divided by the first-year annualized failure rate (AFR). This is a suitable approximation for small failure rates, and we intend it to represent a *first year* MTBF. The annualized failure rate for a drive is derived from time-to-fail data collected during a reliability-demonstration test (RDT). Factory reliability-demonstration tests (FRDT) are similar but are performed on drives pulled from the volume production line. For the purposes of this paper, we assume that any concept that applies to an RDT also applies to an FRDT.

Seagate Reliability Tests

At Seagate® Personal Storage Group in Longmont, Colorado, desktop disc drive reliability tests are normally conducted in ovens at 42°C ambient temperature to provide accelerated failure rates. In addition, the drives are operated at the highest possible duty cycle (a drive's duty cycle is defined by the number of seeks, reads and writes it performs over a specific time period). We do this to discover as many failure modes as possible during the product development cycle. By fixing any problems we may see at this stage, we can make sure that our customers won't see the same problems.

Estimating Weibull Parameters

Let's assume we have an RDT with 500 drives, all run for 672 hours at 42°C ambient temperature. During this test, further assume that we observe three failures (at 12, 133 and 232 hours). This means that, of the 500 drives tested, 497 ran the entire test without failing. To analyze and extrapolate from the test results, we perform Weibull modeling using SuperSmith software from Fulton Findings.¹ Specifically, we use the Maximum Likelihood method to estimate the Weibull-distribution parameters Beta (a shape parameter) and Eta (a scale parameter).

In tests with five or fewer failures, the Beta parameter cannot be well defined by the test data. Because such cases are common in drive testing, we analyze the data using a WeiBayes² approach. This approach requires that we estimate the Beta parameter using historical data. In the desktop-products lab, we are currently assuming that Beta = 0.55. This value is based on the manufacturing data shown in the following table, which includes all desktop products tested prior to March 1999.

1. SuperSmith, Fulton Findings, WinSMITH and WinSMITH Weibull are trademarks of Fulton Findings, 1251 W. Sepulveda Blvd., #800, Torrance, CA 90502, USA
2. Abernethy, Dr. Robert B., The New Weibull handbook, Second Edition, published by the author, 1996, Chapter 5.

T E C H N O L O G Y P A P E R

S E A T A G A T E

F R O M



INTELLIGENCE

Corporate Headquarters
 Scotts Valley, California, USA +1-831-438-6550

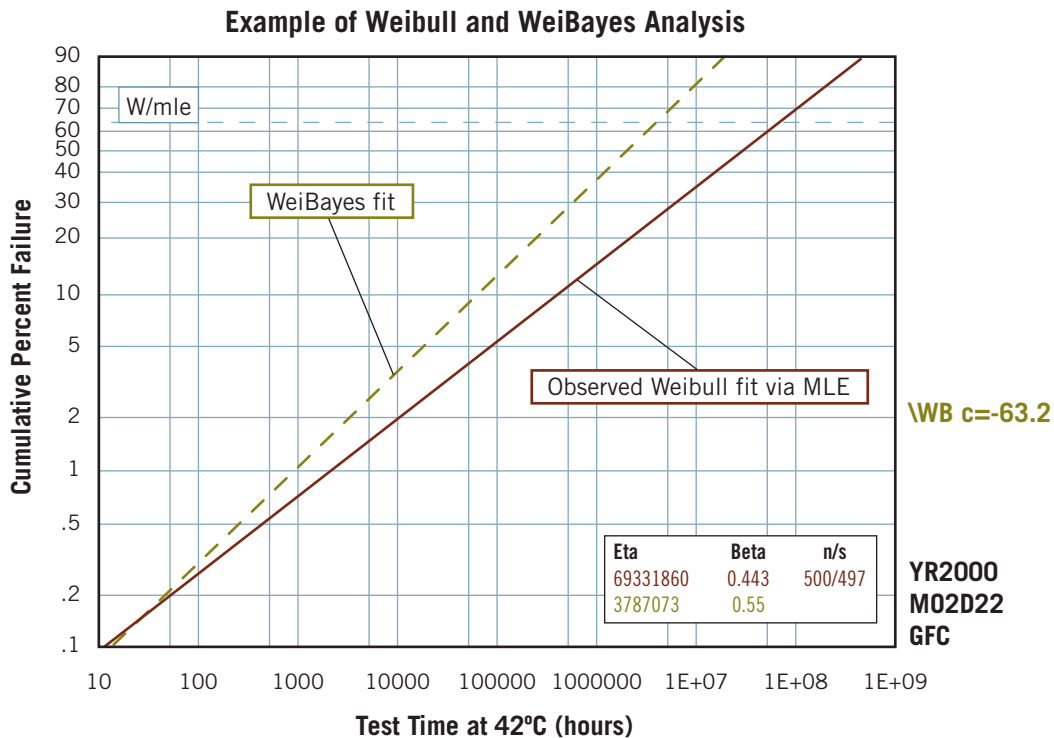
Asia/Pacific Headquarters
 Singapore +65-488-7200

Europe, Middle East and Africa Headquarters
 Boulogne-Billancourt, France +33 1-41 86 10 00

Desktop drive site	Database	Mean Beta	Standard Deviation of Beta
Longmont	37 RTD, 5 FRDT	0.546	0.176
Perai	2 RTD, 4 FRDT	0.617	0.068
Wuzi	1 RTD	0.388	n/a
Pooled desktop data	49 Tests	0.552	0.167

The graph below shows the results of both the Weibull and WeiBayes analysis. The solid line in the figure below shows Weibull Beta and Eta parameters (Beta = 0.443, Eta = 69331860) estimated using the Maximum Likelihood³ (MLE) approach on only 3 failures out of 500 drives. As mentioned before, these results are considered less accurate than those of the WeiBayes method for small failure rates.

The results of the WeiBayes method (with Beta = 0.55) are shown as a dashed line in the figure below. Because 672 test hours at 42°C should be a sufficiently long run time for an RDT, we use our internal *test exit confidence level*⁴ of 63.2 percent for the WeiBayes analysis. The WeiBayes calculations indicate that, at 42°C, given a historical Beta = 0.55, a reasonable value for Eta is 3,787,073 hours.



The next step in the analysis is to convert the value for Eta that was based on tests at 42°C to a value that reflects our specified operational temperature (25°C). Using the Arrhenius Model,⁵ an acceleration factor of 2.2208 can be used to account for this difference in temperature. Therefore, the value for Eta at 25°C (Eta25) is assumed to be equal to the value for Eta at 42°C (Eta42) times 2.2208, or 8,410,332 hours.

3. Abernethy, Dr. Robert B., The New Weibull handbook, Second Edition, published by the author, 1996, Appendix D.

4. Earlier in the RDT, a larger confidence level would be used to reflect the uncertainty in Weibull parameter estimation due to the limited run time.

5. Nelson, Wayne, Applied Life Data Analysis, John Wiley & Sons, 1982.

Applying the Estimated Weibull Parameters to Estimate First-Year MTBF

Using the temperature-adjusted estimated values of the Weibull Beta and Eta parameters, we can calculate the cumulative-percent-failure rate at any time. By subtracting the cumulative-percent-failure rates for two different times (t1 and t2), and using appropriate values for Beta and Eta25, we can estimate the percent of drives that are likely to fail at 25°C during any time interval from t1 to t2.

To estimate the AFR for the first year of drive operation in a desktop computer setting, we assume that the drive is used at a rate of 2,400 power-on-hours (POH) per customer year. In addition, we assume that drives are subjected to a 24-POH integration period by the device manufacturer. Because any drives that fail during this period are returned to Seagate and are not shipped to the end-user, they are not counted in the first year AFR and MTBF.

Based on these assumptions (100% duty cycle, Eta25 = 8,410,332 hours, Beta = 0.55, and 2,400 POH per year) the percent failure rate in the first customer year after integration can be calculated as the percent failure rate between 24 hours (t1) and 2,424 hours (t2). The results of this calculation are shown in the table below, which derives a first-year MTBF from the RDT data.

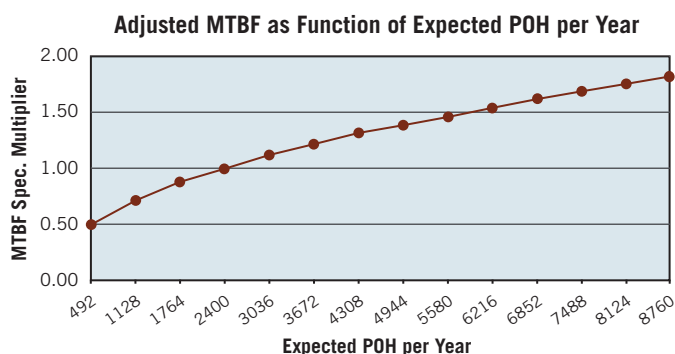
Input area:	2,400 hours per year
Weibull shape factor (Beta):	0.55
Weibull scale factor (Eta):	8,410,332
P(fail), 0 to 2,424 POH per year:	1.123%
P(fail), 0 to 24 hours:	– 0.089%
First-year AFR	= 1.0338% (before rounding)
POH per year:	2,400
First-year AFT:	÷ 0.010338
First-year Weibull MTBF	= 232,140

Accounting for Actual User Conditions

The calculations above suggest that if a customer were to use our drive at 25°C and 2,400 POH per year, the expected customer MTBF in the first year would be 232,140. However, these conditions may not always apply to the consumer electronics environment. For example, in some consumer devices, the drive may be powered on almost 100 percent of the time and yearly usage rates may be much higher than 2,400 POH. In other devices, such as video game players, the POH per year may be relatively low. The following section describes how we can adjust the calculated MTBF so that it applies to various usage levels, duty cycles and ambient temperatures.

Usage Levels

To account for variation in MTBF due to different levels of usage, we may use the MTBF adjustment curve shown at right. For example, to adjust an MTBF from 2,400 POH per year to a maximum usage rate of 8,760 POH per year, the MTBF would be increased by 1.8 times. Conversely, for low-usage environments, as in some video games, the MTBF may be decreased by as much as a factor of two.



Temperature

Next let's look at the effects of elevated operating temperature. The same Arrhenius Model that we used to develop an acceleration factor may also be used to generate an MTBF temperature derating-factor (DF) curve. The following table shows the decrease in first-year MTBF (at 100% duty cycle) as ambient temperature increases above 25°C.

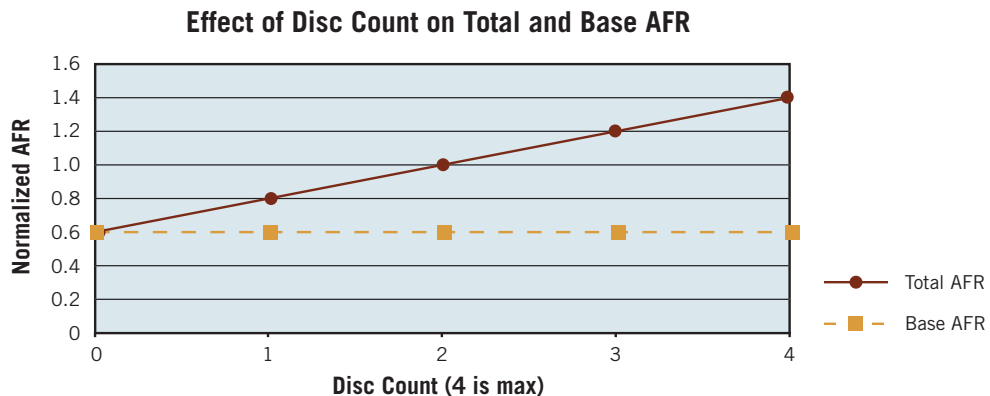
Temp (°C)	Acceleration Factor	Derating Factor	Adjusted MTBF
25	1.0000	1.00	232,140
26	1.0507	0.95	220,533
30	1.2763	0.78	181,069
34	1.5425	0.65	150,891
38	1.8552	0.54	125,356
42	2.2208	0.45	104,463
46	2.6465	0.38	88,123
50	3.1401	0.32	74,284
54	3.7103	0.27	62,678
58	4.3664	0.23	53,392
62	5.1186	0.20	46,428
66	5.9779	0.17	39,464
70	6.9562	0.14	32,500

From the table above, it is clear that as the ambient temperature rises, the derating factor and the adjusted MTBF become significantly smaller. For example, at 42°C, we find the 2.2208 acceleration factor referred to previously in this analysis. Its reciprocal, 0.45, is the DF value, which indicates that the MTBF at 42°C is less than half as long as the MTBF at 25°C.

Duty Cycle

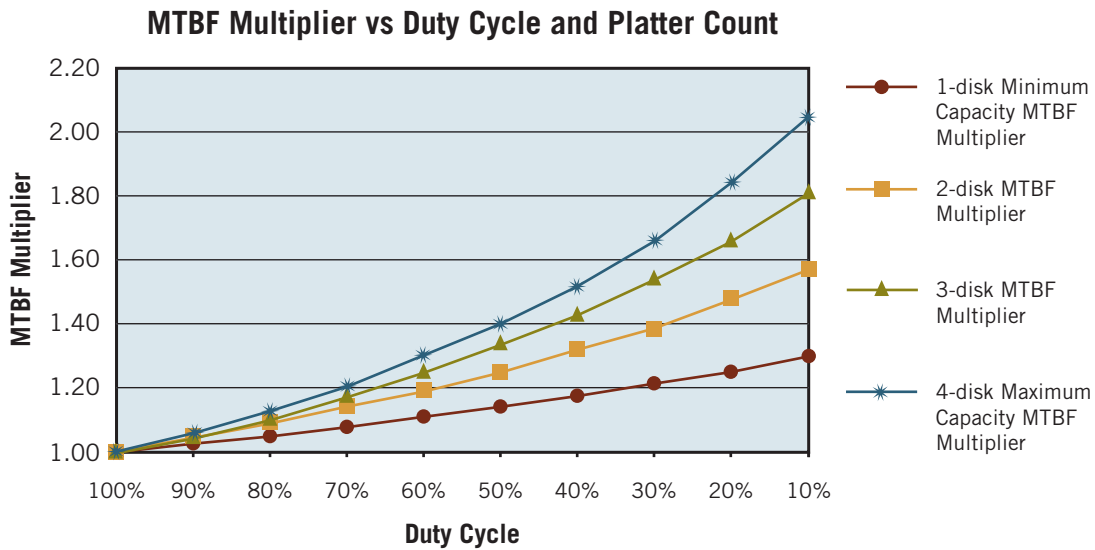
Most disc drives in PCs are operated at duty cycles of 20 percent to 30 percent. However, consumer electronics devices may have lower or higher duty cycles. Seagate has measured average daily data-transfer rates on existing consumer electronics devices and found duty cycles as low as 2.5 percent.

To compare the effect of a 2.5 percent duty cycle with that of a 100 percent duty cycle (used in RTD testing), we can examine the effect of duty-cycle-dependent components in the drive relative to other components. The number of duty-cycle-dependent components in a hard disc drive is proportional to the number of discs in the drive. The relationship between disc count and AFR is shown in the following figure. In this graph, the area below the dotted line indicates the “base” or nonduty-cycle-dependent failure rate for a hypothetical drive with no discs (or a drive that is not reading, writing or seeking). The solid line indicates estimated failure rates as a function of the number of discs present.



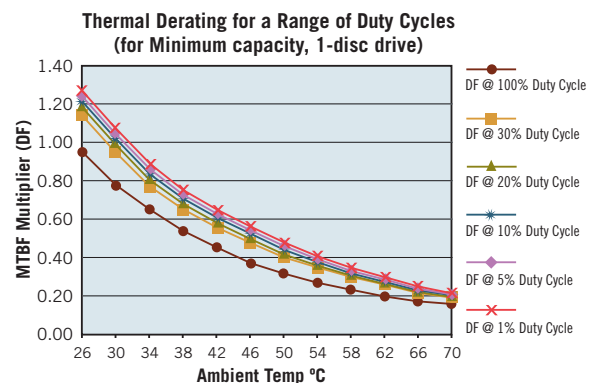
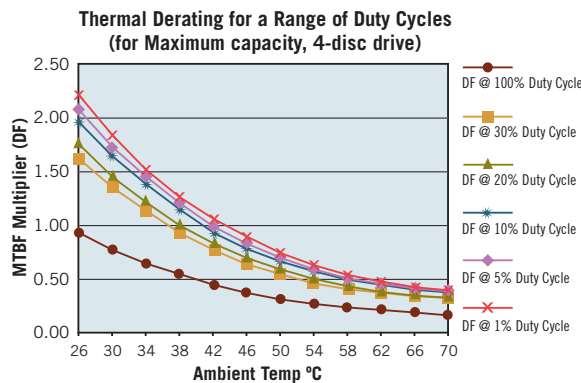
From the previous graph it is clear that reducing a drive's duty cycle reduces only the duty-cycle-dependent failures (those between the dotted and solid line). Using the ratio between duty-cycle-dependent and total failures, we can estimate the effect of duty cycle on AFR. For example, consider a four-disc drive with a total AFR of 1.4 percent and a base AFR of 0.6 percent. Reducing the duty cycle would reduce the failures by the factor $[(1.4 - 0.6)/1.4] = 57$ percent. In accounting for reduced duty cycle on a four-disc drive, therefore, we can only reduce 57 percent of the failures; the remainder are treated as independent of duty cycle.

The resulting MTBF multipliers for drives with different numbers of discs are shown in the following figure.



Combining Multiple Factors

To continue the analysis, we combine a range of duty cycles and temperature derating factors (DF) for several different drives. The figure on the left shows MTBF multipliers at a variety of duty cycles and temperatures for a high-capacity, 4-disc drive. The figure on the right shows the same multipliers as applied to a drive with only one disc. As shown in these figures, depending on the duty cycle and the ambient temperature of the drive in the customer's PC, the first-year effective MTBF may be greater than, equal to, or less than the MTBF that we estimate based on in-house testing. For the one-disc drive, the effects of varying duty cycles are less significant and the MTBF multipliers tend to be significantly smaller.





Reliability after the First Year

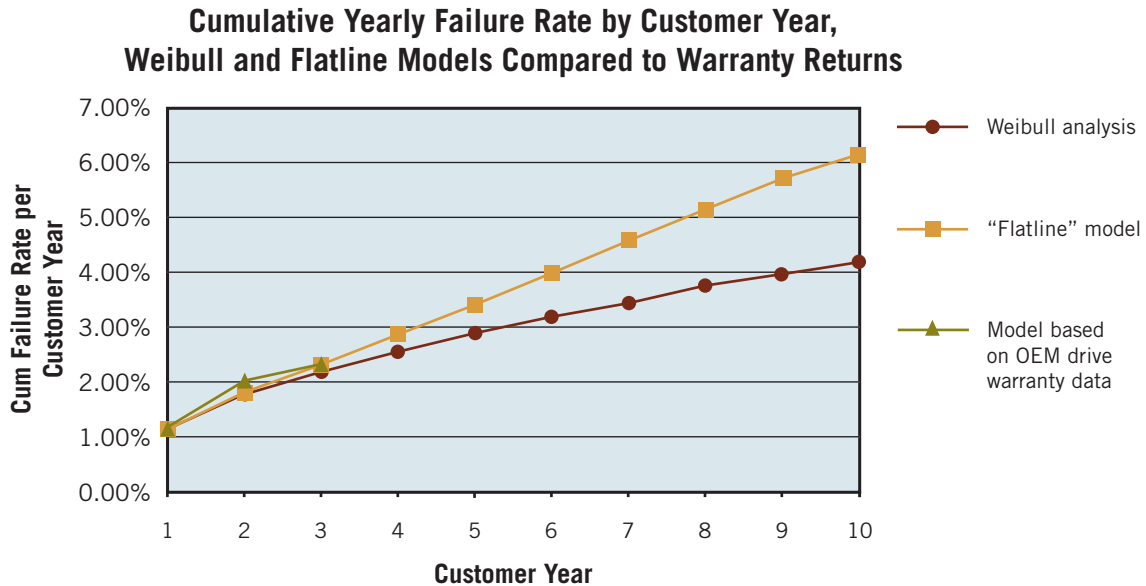
The Weibull distribution of time-to-failure, with a Beta less than one, is a distribution of decreasing failure probability over time. Because of this, MTBF values for a drive's first year in the field are likely to be lower than for subsequent years. What would the failure rate or MTBF look like if averaged over the entire useful lifetime of the drive? Three possible methods for estimating reliability over a drive lifetime are listed below:

- We could use the Weibull [Beta, Eta25] analysis to estimate failures after the first year. However, this would require extending the RDT test results up to an order of magnitude beyond the duration of the test. This would not be a very conservative practice.
- We could use data from the Seagate warranty-return database, from which we may estimate the returns in the second and third years relative to the number of drives returned in the first year. This data is only applicable to the first three years, which is the limit of most current Seagate desktop-drive warranties, but it has the advantage of being based on only Seagate desktop products.
- We could assume a model that would “flatline,” or maintain a constant failure rate after the end of the first year. In other words, we could assume that after the first year, all yearly failure rates would all be equal to the second-year failure rate. Since failure rates would, if anything, decline over time, this would be a conservative estimate of averaged MTBF for the life of the drive.

These models are compared in the table below.

		MODEL:					
		Weibull		Warranty Data (OEM only)		Flatline Model	
Year	Cumulative power-on hours	Yearly failure rate	Cumulative failure rate	Yearly failure rate	Cumulative failure rate	Yearly failure rate	Cumulative failure rate
1	2,400	1.20%	1.20%	1.20%	1.20%	1.20%	1.20%
2	4,800	0.55%	1.75%	0.78%	1.98%	0.55%	1.75%
3	7,200	0.43%	2.18%	0.39%	2.37%	0.55%	2.30%
4	9,600	0.37%	2.55%			0.55%	2.86%
5	12,000	0.33%	2.88%			0.55%	3.41%
6	14,400	0.30%	3.18%			0.55%	3.96%
7	16,800	0.28%	3.46%			0.55%	4.51%
8	19,200	0.26%	3.72%			0.55%	5.06%
9	21,600	0.24%	3.96%			0.55%	5.62%
10	24,000	0.23%	4.19%			0.55%	6.17%

To further illustrate the differences between these models, let's look at the cumulative percent failure rates for the three different models, each assuming a 200,000-hour first-year MTBF:



As the graph above shows, the "flatline" model is less aggressive than the pure Weibull model, and comes close to the model based on Seagate warranty returns in the first three years. For simplicity, and to provide a conservative estimate, we have chosen to use the flatline model for our calculations.

Using the flatline model, the results of lifetime-averaged MTBF compared to first-year MTBF may be summarized as follows:

Average values for years 1 through 3:

Failures per year	0.768%
MTBF	312,500
Improvement over noncorrected MTBF (232,140 hours)	1.56

Average values for years 1 through 5:

Failures per year	0.682%
MTBF	352,113
Improvement over noncorrected MTBF (232,140 hours)	1.76

Average values for years 1 through 10:

Failures per year	0.617%
MTBF	389,105
Improvement over noncorrected MTBF (232,140 hours)	1.95

These calculations indicate that you multiply the first-year MTBF (at the appropriate duty cycle and ambient temperature) by 1.56 to estimate the averaged MTBF over a three-year drive lifetime. Similarly, to estimate the average MTBF over a drive lifetime of five or ten years, multiply the first year MTBF by 1.76 or 1.95, respectively.



Putting it All Together

By combining the multipliers and derating factors described above, we can convert the Seagate-specified MTBF (first year, at 25°C ambient temperature, 2,400 POH per year and 100 percent duty cycle) into an MTBF that applies to a drive in a customer's device at an appropriate ambient temperature and duty cycle. We can then estimate the average MTBF over the drive's lifetime.

The following example demonstrates the calculation of first-year and drive-lifetime MTBF for a drive operated at 2,400 POH per year at an ambient operating temperature of 38°C, a duty cycle of 30 percent and a five-year useful life.

First-year MTBF:	232,140 hours	(based on Weibull parameters: Beta, Eta25)
	× <u>0.90</u>	(temp derating for 38°C and 30% duty cycle)
Customer first-year MTBF:	208,926 hours	
Customer MTBF:	208,926 hours	
	× <u>1.76</u>	(factor for averaging over five-year lifetime)
Customer drive-lifetime MTBF:	367,710 hours	

As a final example, consider the case of a 1-disc Seagate drive with a specified first-year MTBF of 500,000 hours, which is being operated in a consumer electronics device for a usage rate of 2,920 POH per year (eight hours a day, seven days a week), an ambient temperature of 42°C and a duty cycle of 5 percent.

First-year MTBF:	500,000 hours	(based on Weibull parameters: Beta, Eta25)
	× 1.09	(adjustment for 2,920 POH per year)
	× 0.59	(derating for temperature of 42°C and 5% duty cycle)
	× <u>1.95</u>	(factor for averaging over 10-year drive lifetime)
Customer average MTBF:	627,023 hours	

Conclusion

The method outlined above allows us to use Seagate laboratory test data to estimate the reliability of drives in desktop computers and consumer electronic devices in *real-world* settings. The method can be summarized as follows:

- Use Weibull or historical RDT/FRDT test data to estimate Weibull parameters for drive tests.
- Use WeiBayes analysis of test data for a specific type of drive to estimate first-year AFR and MTBF under RDT test conditions.
- Correct for any differences from the assumed usage rate of 2,400 POH per hour.
- Correct these values to take into account differences between RDT conditions and the *real-life* temperature and duty-cycles experienced by the drive after it reaches the customer.
- Extend the first-year customer reliability estimates over a three- to ten-year drive lifetime, using the conservative assumption that failure rates remain constant after the drive's first year in the field.

In conclusion, this method provides a mathematically reasonable method for using Seagate test results to estimate drive reliability in consumer electronics.