Improvements in Automated Reliability Growth Plotting and Estimations

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Overview and outline

- Review of learning curve theory and "ideal" data.
- Some common misconceptions about growth slope.
- Real world differences as applied to field data.
- A computer friendly way of following them that helps to avoid the errors in judgment is discussed.
- Review Duane's data and recommendations.
- Weighted least squares fit through the last point".
- Review the result of applying "least squares fit" and "weighted least squares fit – through the last point".

Background and introduction

- Failure data from a fielded system.
- There are numerous sources of noise in field failure data compared with ideal data:
  - Imperfect corrective action
  - Multiple units in the field of varying degrees of maturity
  - Not all have the same corrective actions implemented
  - Time to return failed units from the field
  - Some fielded units have design changes that others do not have
- Reliability Growth profile of all the units collectively.
- Improvement of weighted CG and the last point.

The probability distribution of failure modes

- White noise contains all frequencies in equal proportion.
- Successive sweeps are always different from each other, yet the waveform always "looks" the same.
- These probabilities are evenly spaced when displayed on a log scale.
- This is a valid model to exercise for determining the effects of corrective action effectiveness.

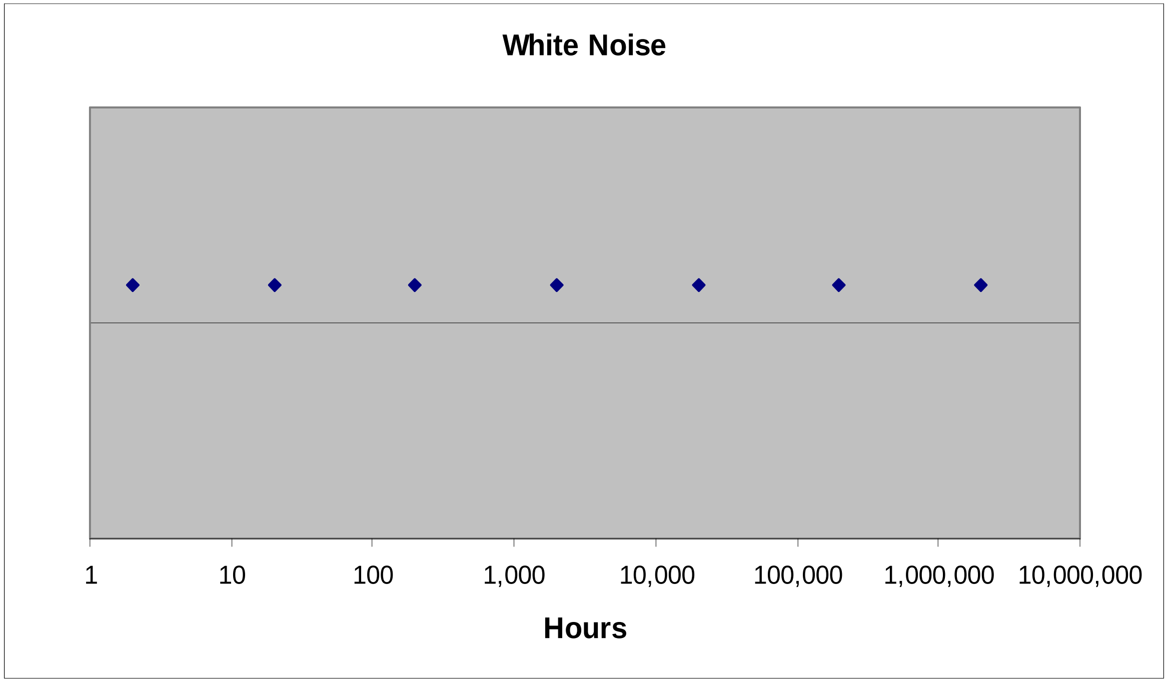
We will exercise “scripted” white noise data

Test Times for White Noise

Failure Mode	Test Time (hours) @ failure
1	20
2	200
3	2,000
4	20,000
5	200,000
6	2,000,000

Probabilities are evenly spaced on a log scale

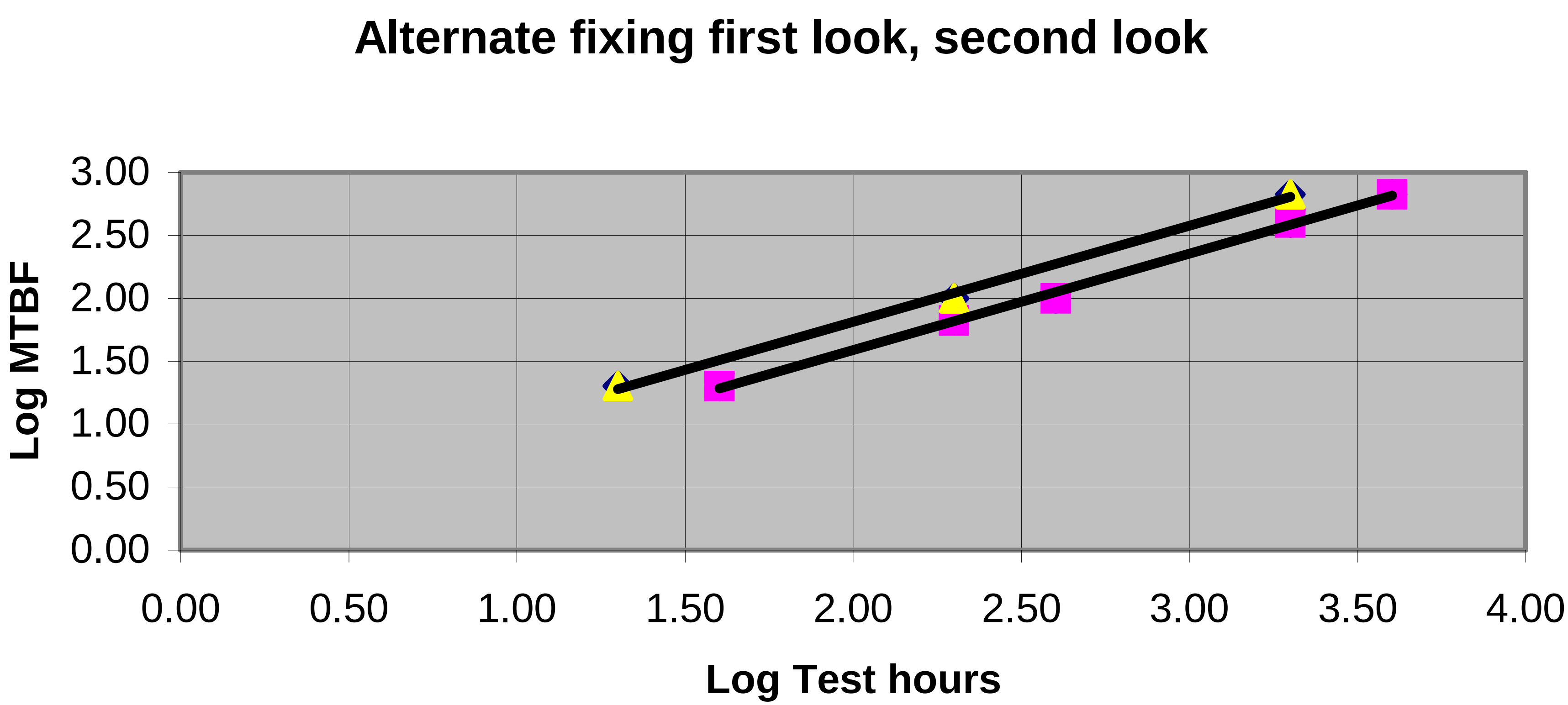
- It consists of an infinite number of failure modes with the probability of each one a common multiple of the previous one, +/- uncertainty.



What if every failure had to be seen twice?

Corrective Action Effectiveness	Test Time @ Failure	Cumulative MTBF	Cumulative Failures	Log test Times	Log MTBF
100%	20	20	1	1.30	1.30
100%	200	100	2	2.30	2.00
100%	2,000	667	3	3.30	2.82
50%	20	20	1	1.30	1.30
50%	40	20	2	1.60	1.30
50%	200	67	3	2.30	1.82
50%	400	100	4	2.60	2.00

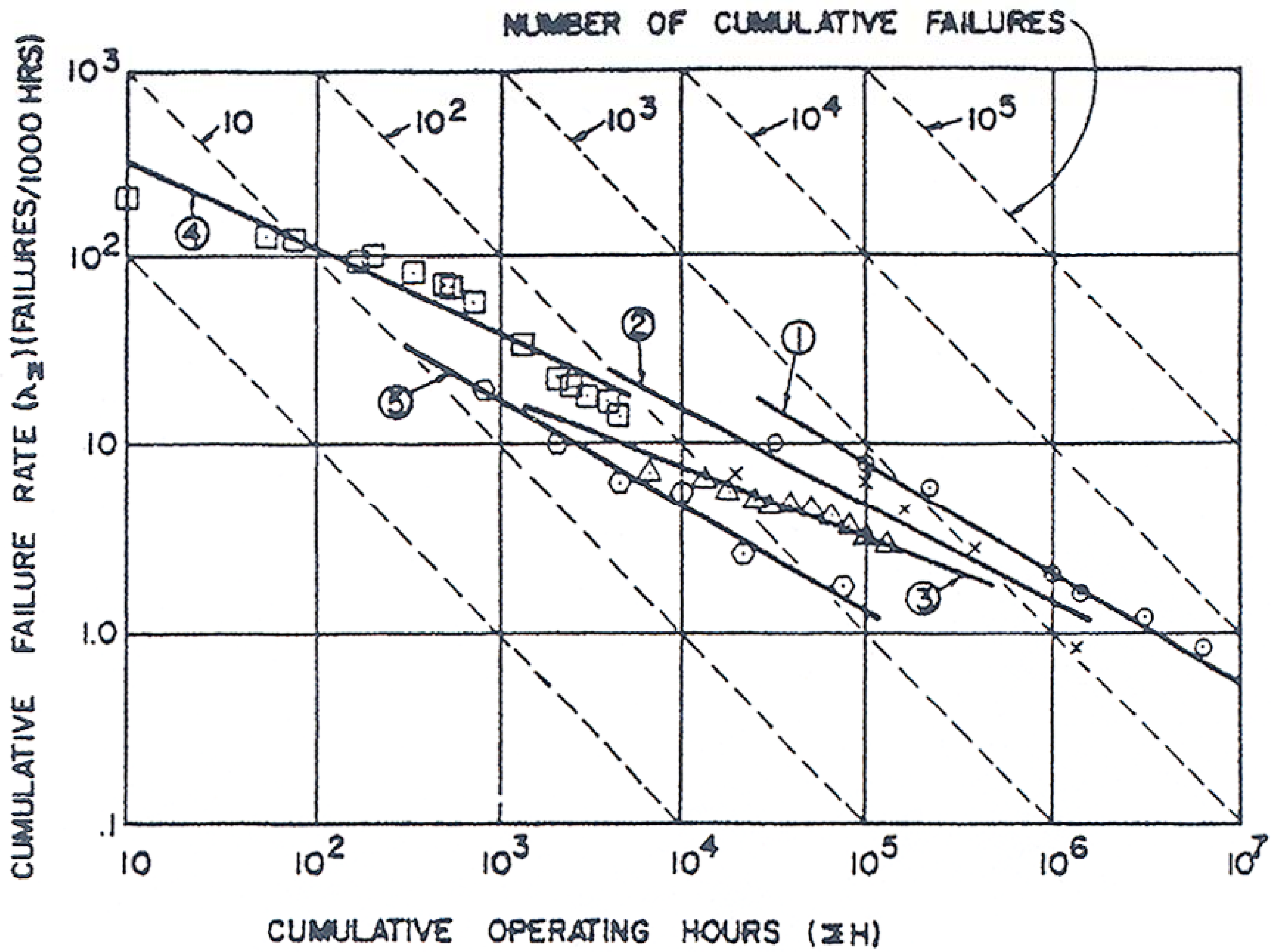
C/A effectiveness displaces the line



Variability of failure mode probability

- Corrective actions are not perfect.
- Simultaneous testing of multiple field units.
- Corrective action not implemented in all units.
- Time to correct failures for field returns may be long.
- Design changes can significantly affect reliability of new items put in the mix with fielded units.
- Not all units see the same environment.

Duane saw a consistent pattern for 5 systems



E. O. Codier (Ref 2)* gave three rules

- The latter points, having more information content, must be given more weight than earlier points and
- The normal curve fitting procedure of drawing the line through the "center of gravity" of all the points should not be used.
- Unless the data are exceptionally noisy, start the line on the **last data point** and seek the region of **highest density of points** to the left of it.

*Ernest O. Codier, "Reliability Growth in Real Life", Proceedings, 1968 Annual Symposium on Reliability, New York, IEEE, Jan., 1968, pp 458-469.

J. T. Duane's papers described a method

$$\lambda_c = F / T$$

$$= kT^{(-m)}$$

Cumulative Failure Rate = Σ(Failures)/Σ(Hours)

$$F = kT^{(1-\mathrm{m})}$$

$$\lambda_i = \partial F / \partial T$$

$$= k(1-m)T^{(-m)}$$

$$\lambda_i = (1-m)\lambda_c$$

$$m = slope$$

Instantaneous failure rate, λi, is the time derivative of 'F'. MTBFi (Instantaneous MTBF) is its reciprocal.

The tasks are simple

- Collect data
    - Failure count
    - Hours of test time or
    - Number of test samples (e.g., for one-shot items, rockets).
- Plot on a log-log scale
    - Failure count
    - Hours of test time or
    - Number of test samples (one shot reliability).

B. Dhillon* weighed the latter points more

- "If the plotted points are not independent, then proportional weighting the cumulative number of failures at each point is a reasonable way to improve accuracy of these estimates."
- This technique assigns greater weight to the preceding data point (the most recent one).
- This method is based on the assumption that each data point is plotted m number of times at that point."

* Balbir S. Dhillon, "Reliability Engineering in Systems Design and Operation", 1983, Van Nostrand Company Inc.

We weigh points and go through the last one

- We will do this by giving each point a weight according to its order in the cumulative statistic except for the last point,
- and find the resulting "center of gravity" of those points.
- We also want to go through the last point.
- We will then have an objective way of adhering to Duane's "notes on plotting the line through the points".

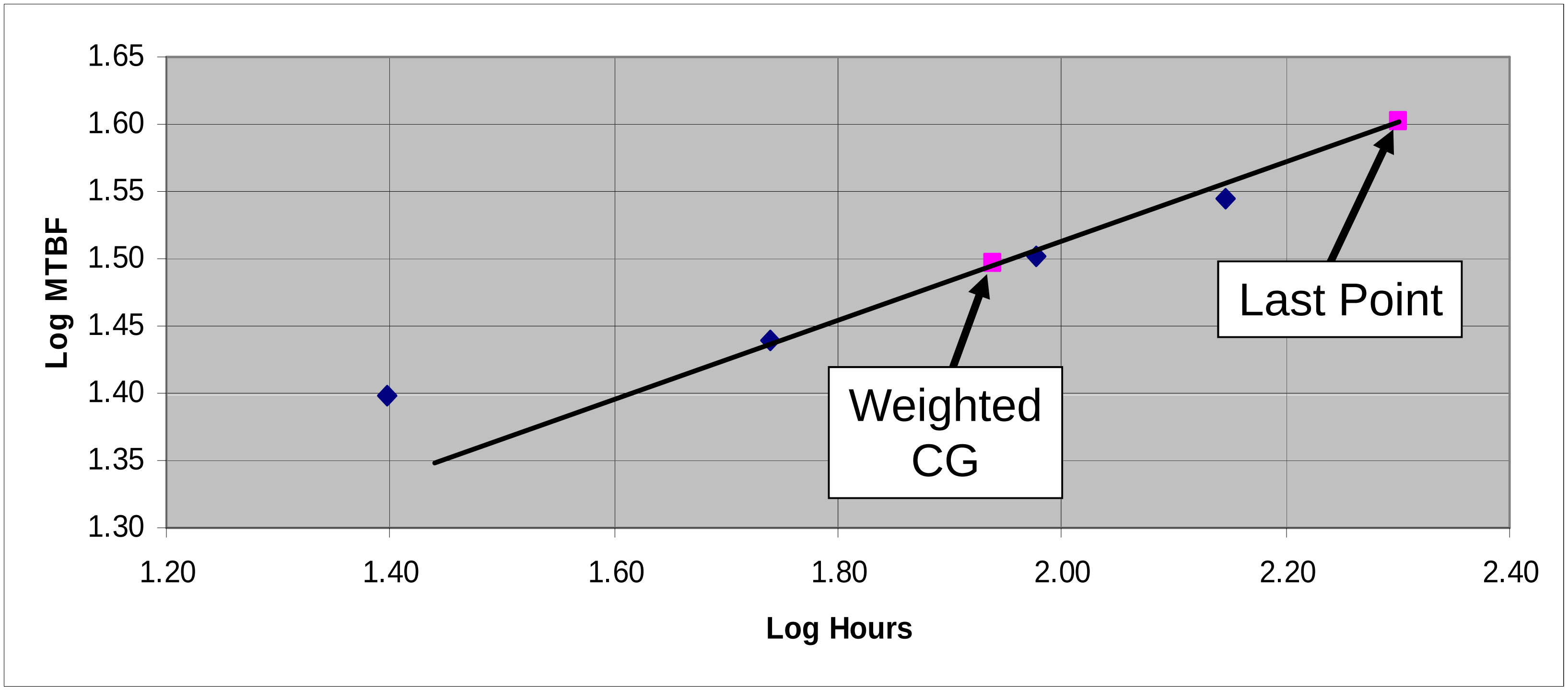
For points 1-4, CGx=1.94, CGy =1.50

ΣF = Weight	ΣH	MTBFc = ΣH/ ΣF	Log (ΣH)	Log (MTBFc)	Weight x Log ΣH	Weight x Log (MTBFc)
1	25	25	1.40	1.40	1.40	1.40
2	55	27.5	1.74	1.44	3.48	2.88
3	95	31.7	1.98	1.50	5.93	4.50
4	140	35	2.15	1.54	8.58	6.18
5	200	40	2.30	1.60	-	-
10			1.94	1.50	19.40	14.96

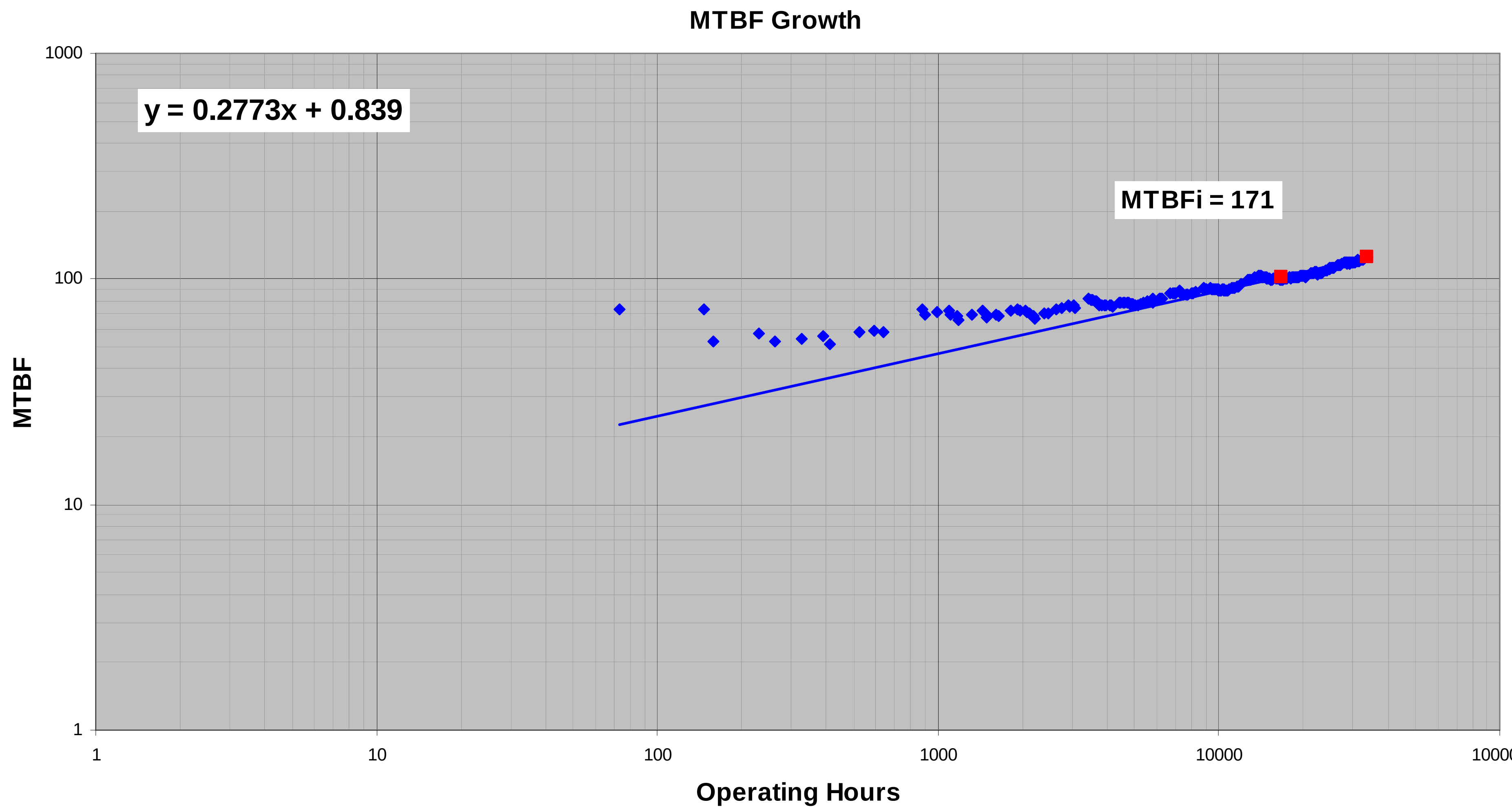
19.40/10

14.96/10

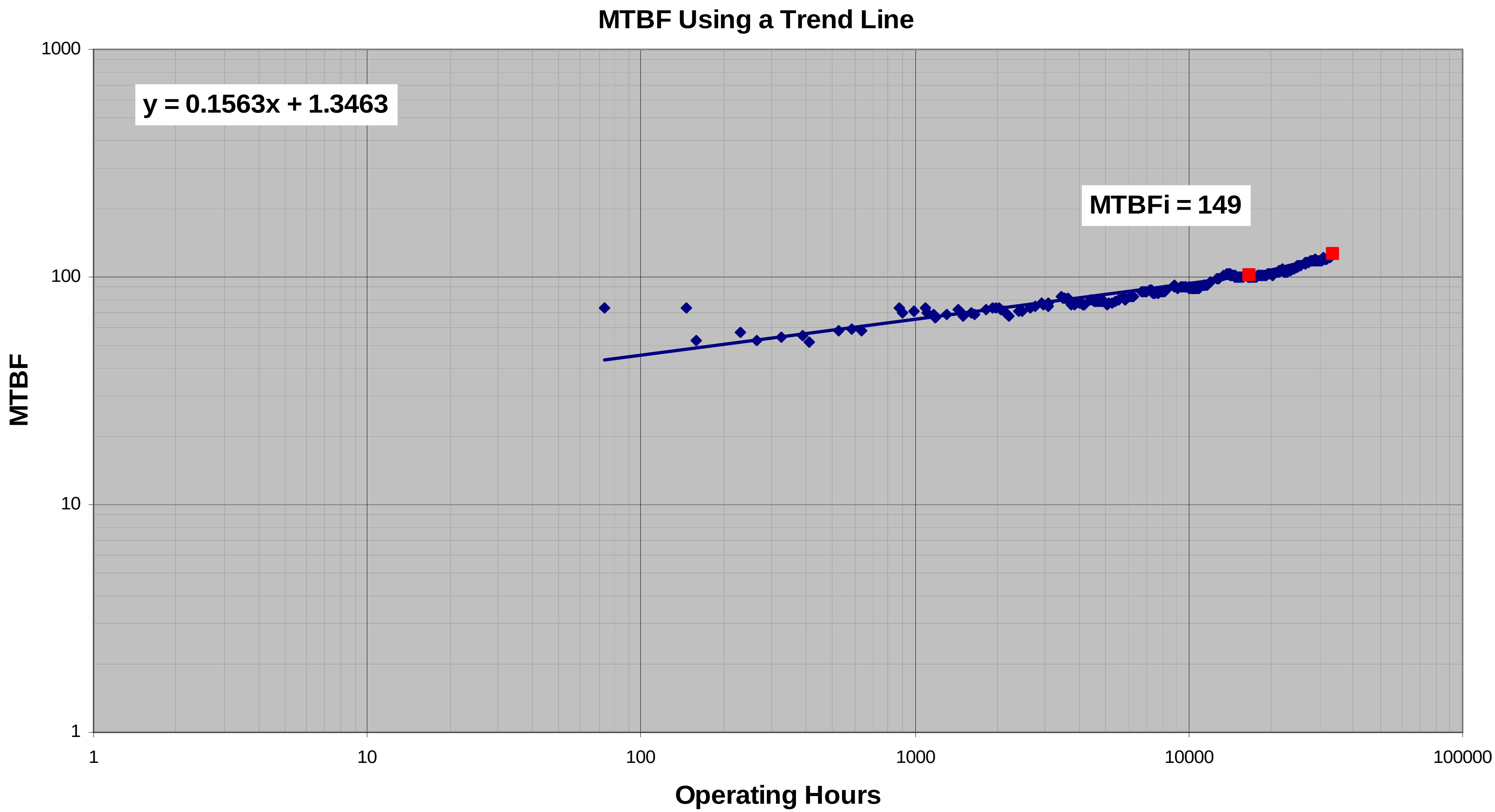
Draw the line through the CG, the last point



Duane's method follows the change in slope



A trend line does not follow the slope change



Trend line resulted in a 54% increase in error

Time (Months)	Moving Ave. MTBF	MTBFi, Wt, Last Point	Wt'd, Last Point Error	MTBFi Trend Line	Trend Line Error
0	69	118	49	69	0
3	81	69	12	78	3
6	107	100	7	81	26
9	112	103	9	86	26
12	131	137	6	95	36
15	134	131	3	102	32
18	128	117	11	112	16
21	121	129	8	117	4
24	112	124	12	119	7
27	137	139	2	128	9
30	167	157	10	138	29
33	197	171	26	149	48
Sum of errors			**155**		**236**
Average error			**13**		**20**

Summary and conclusions

- The method initially described by Duane and Codier works best for estimating field MTBF.
- “Noisy” data does not lend itself to MTBFi estimates, but the owner of these fielded units wants to know what he has in the field anyway.
- This paper shows that for typically noisy field test data, significant error is introduced when the conventional approach of using a least squares fit is employed and that following the original recommendations for line drawing is the best way.