

---

# Improvements in Automated Reliability Growth Plotting and Estimations

Wednesday, 1-28-2009, 3:45 PM

Dave Dwyer, BAE Systems

Edward Wolfe, BAE Systems

Jonathan Cahill, BAE Systems

# 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

---

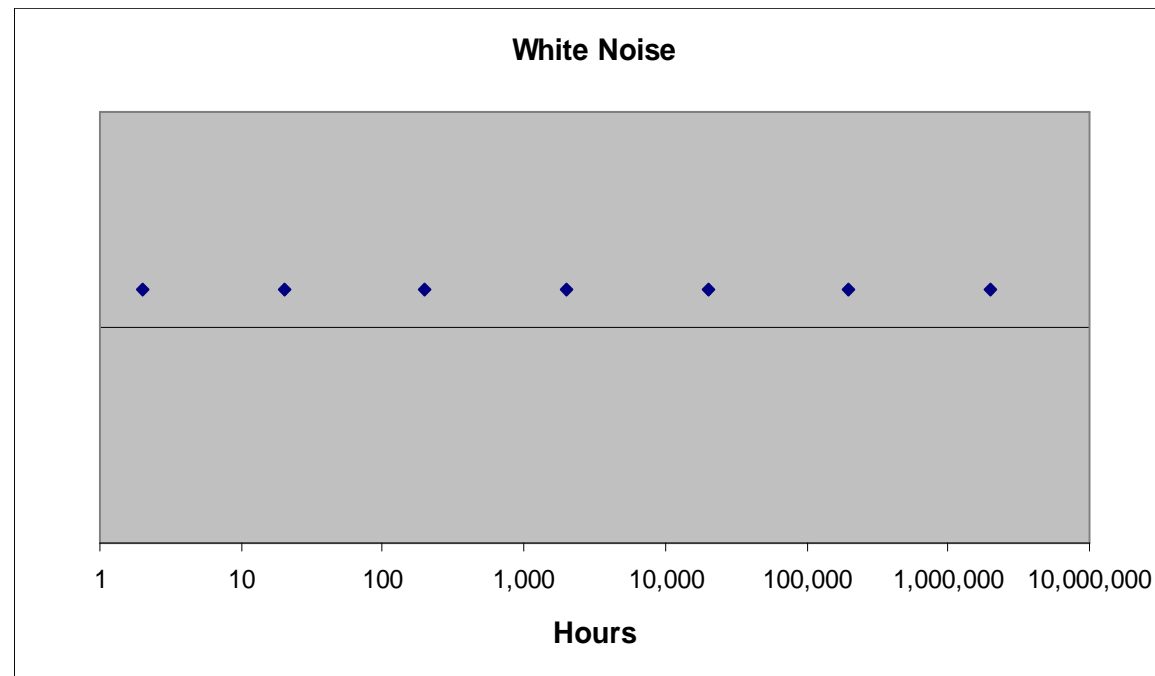
## Test Times for White Noise

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?

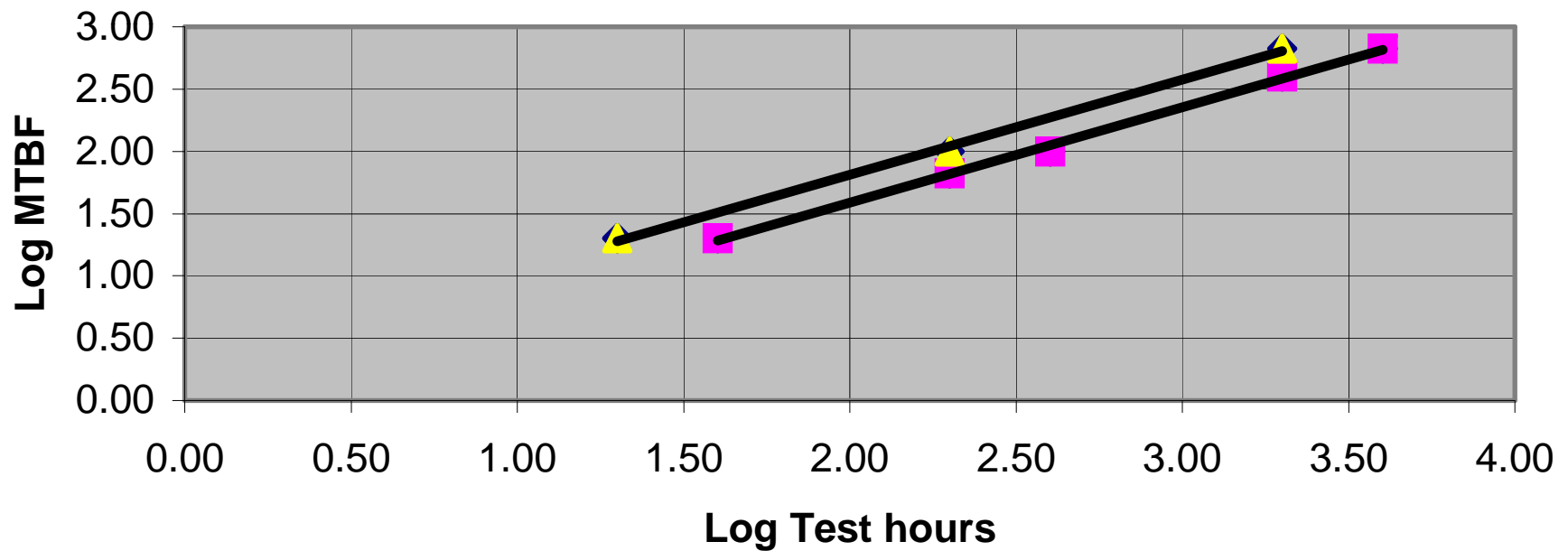
---

<b>Corrective Action Effectiveness</b>	<b>Test Time @ Failure</b>	<b>Cumulative MTBF</b>	<b>Cumulative Failures</b>	<b>Log test Times</b>	<b>Log MTBF</b>
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

---

**Alternate fixing first look, second look**



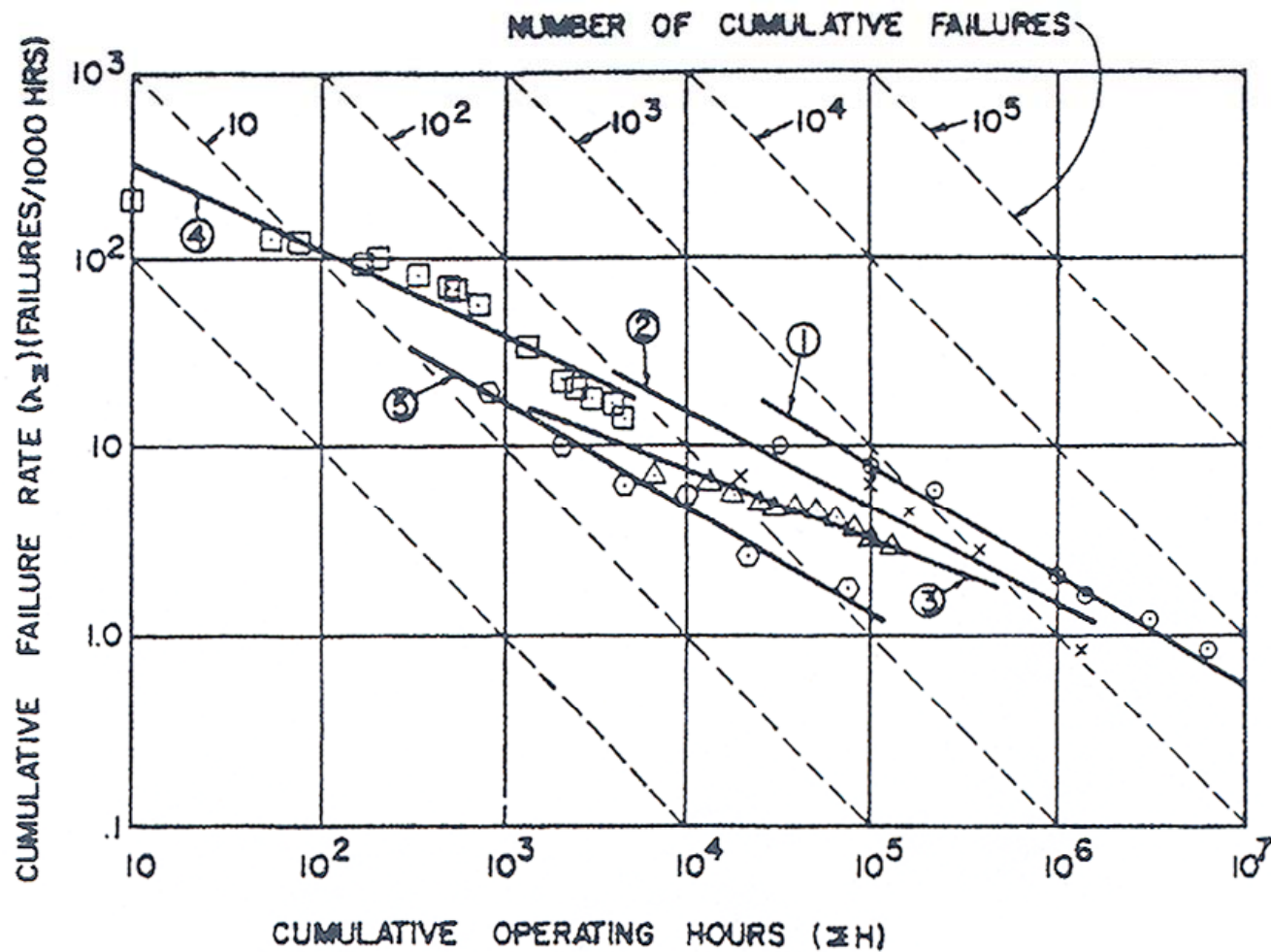


# Variability of failure mode probability

---

- 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 =  
 $\Sigma(\text{Failures}) / \Sigma(\text{Hours})$

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

$$\lambda_i = \partial F / \partial T$$
$$= k(1-m)T^{(-m)}$$

Instantaneous failure rate,  $\lambda_i$ ,  
is the time derivative of 'F'.  
MTBF<sub>i</sub> (Instantaneous MTBF)  
is its reciprocal.

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

$$m = \text{slope}$$

# 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,  $CG_x=1.94$ ,  $CG_y=1.50$

---

$\Sigma F =$ Weight	$\Sigma H$	$MTBF_c =$ $\Sigma H / \Sigma F$	Log ( $\Sigma H$ )	Log ( $MTBF_c$ )	Weight x Log $\Sigma H$	Weight x Log ( $MTBF_c$ )
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

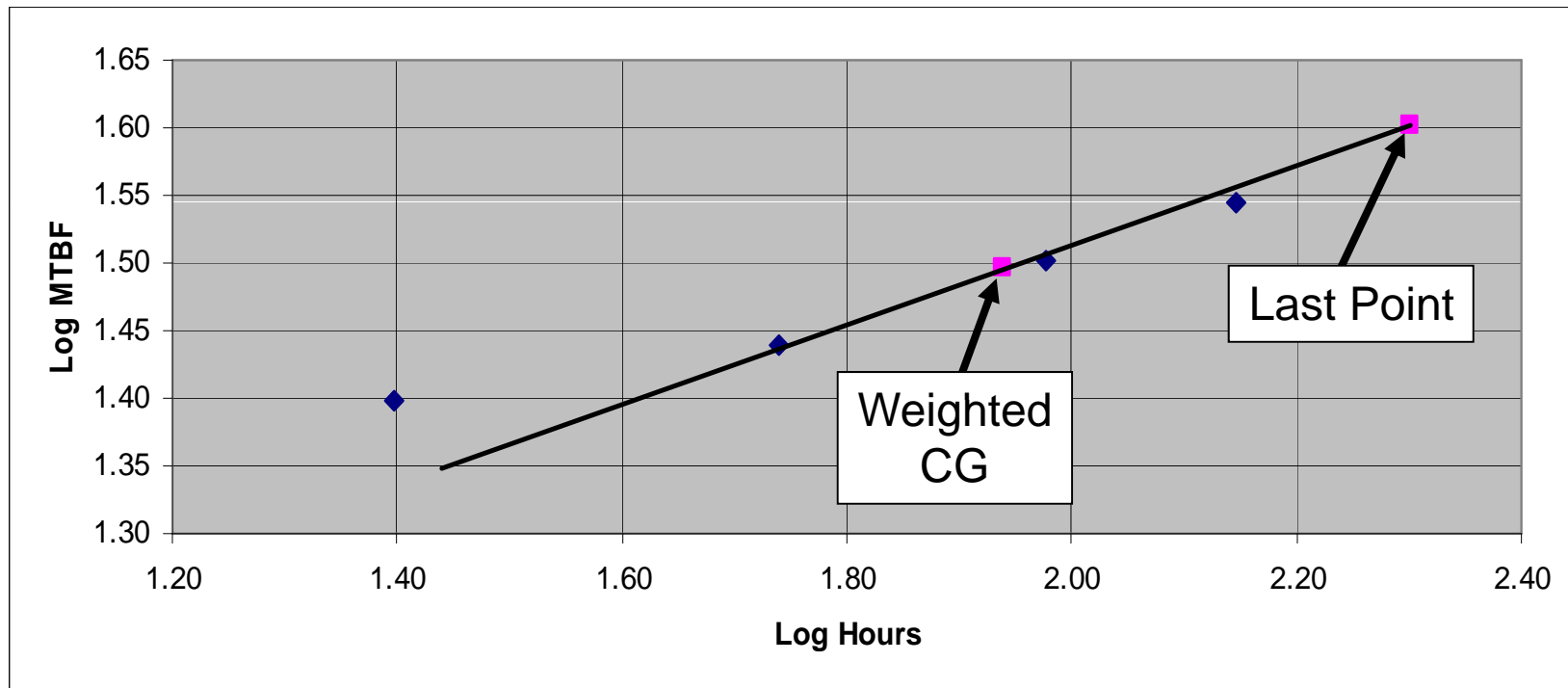
  

14.96/10



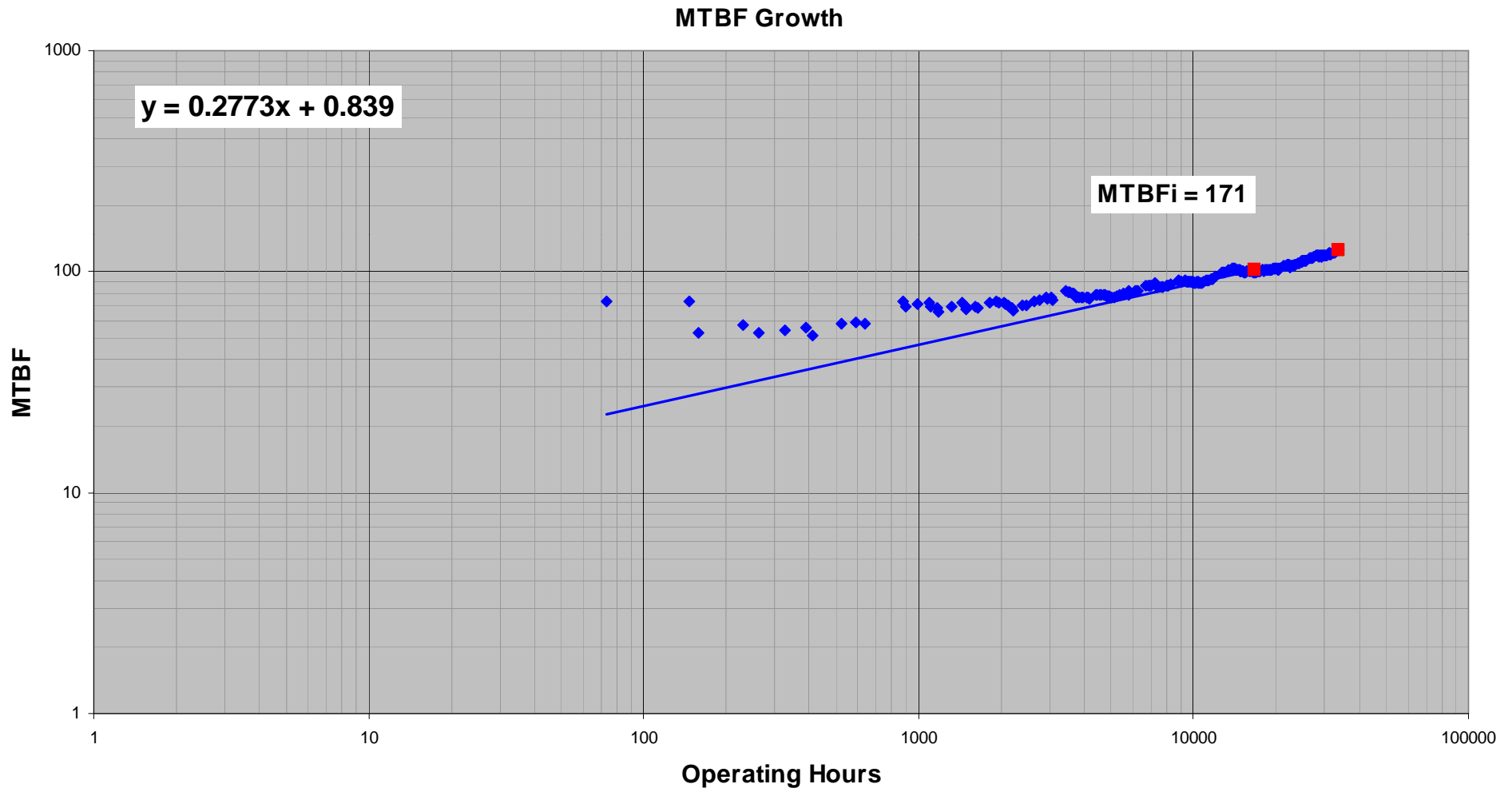
# Draw the line through the CG, the last point

---

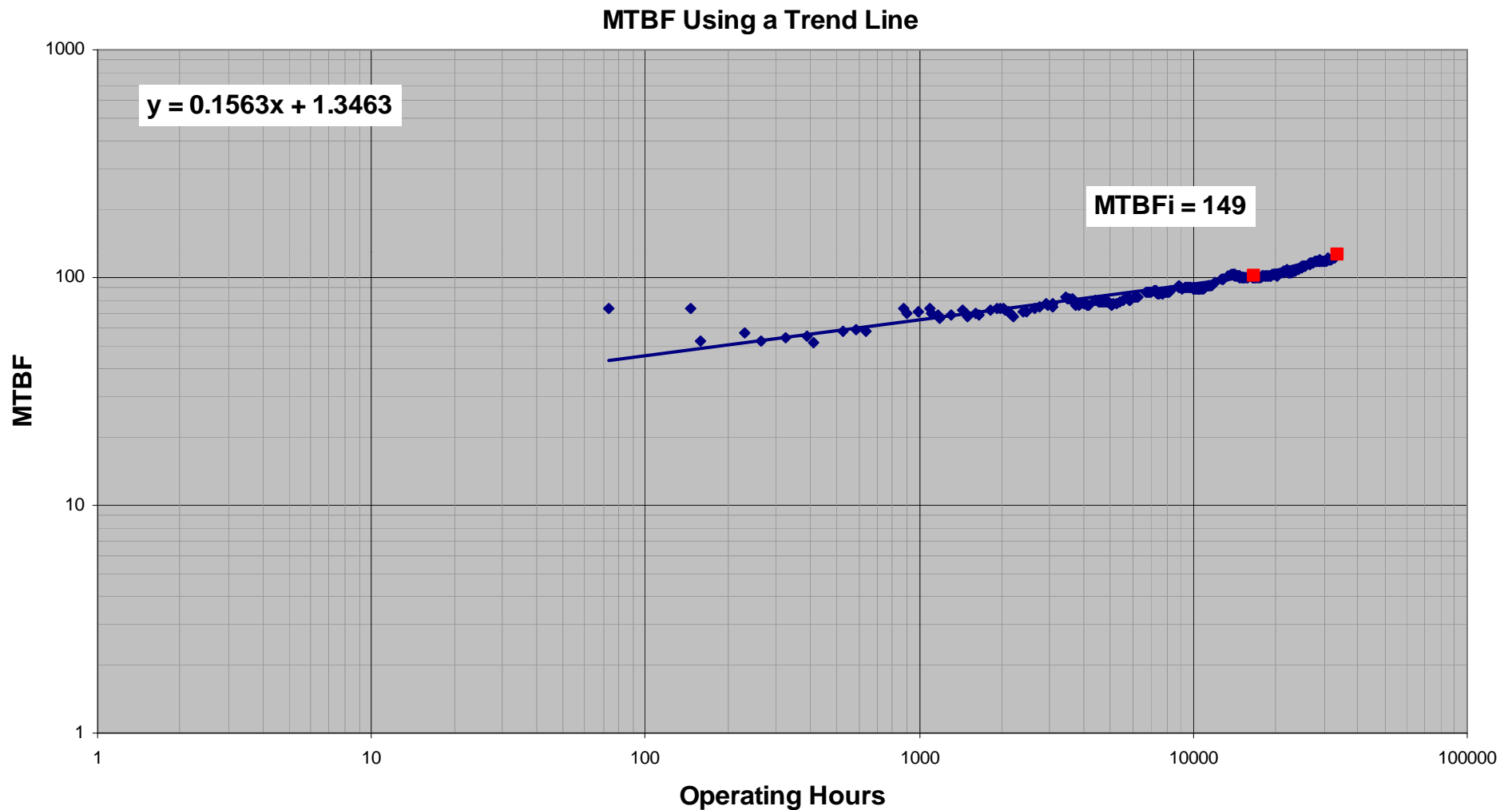


# Duane's method follows the change in slope

---



# 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
<b>Sum of errors</b>			<b>155</b>		<b>236</b>
<b>Average error</b>			<b>13</b>		<b>20</b>

## Summary and conclusions

---

- The method initially described by Duane and Codier works best for estimating field MTBF.
- “Noisy” data does not lend itself to MTBF<sub>i</sub> 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.