Chi-Squared Accelerated Reliability Growth (CARG) Model

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ASQ Presentation

Reference Material for Talk

- DfRSoft.Com → Free Videos/Publication
  - Under Key Publication: A. Feinberg
    - Slides: Chi-Squared Accelerated Reliability Growth Slides ASQ Talk 2015
    - Paper: Chi-Squared Accelerated Reliability Growth (CARG)

      Published: RAMS & IEEE Xplore, January 2013

Software for Chi-Squared Accelerated Reliability Growth

- DfRSoft.Com → Free Trial Copy (3 week trial)
  - Download the appropriate version for your computer
  - Index → Reliability Tools → 10 Accelerated 'Rel Growth' & HALT

Author Bio

- Dr. Alec Feinberg is the founder of DfRSoft. He has a Ph.D. in Physics and is the main author of the book, Design for Reliability, and the principal software developer of DfRSoft Software. Alec has provided reliability engineering services in all areas of reliability including solar, thin film power electronics, defense, microelectronics, aerospace, wireless electronics, and automotive electrical systems. He has provided training classes in Design for Reliability, Shock and Vibration, Quality, Accelerated Testing, HALT, Reliability Growth, Electrostatic Discharge, Dielectric Breakdown, DFMEA and Thermodynamic Reliability Engineering. Alec has presented numerous technical papers and won the 2003 RAMS Alan O. Plait best tutorial award for the topic, “Thermodynamic Reliability Engineering”. Alec is also a major contributing author to the new book on The Physics of Degradation in Engineered Materials and Devices (Chapter 4, Thermodynamic Damage within Physics of Degradation).

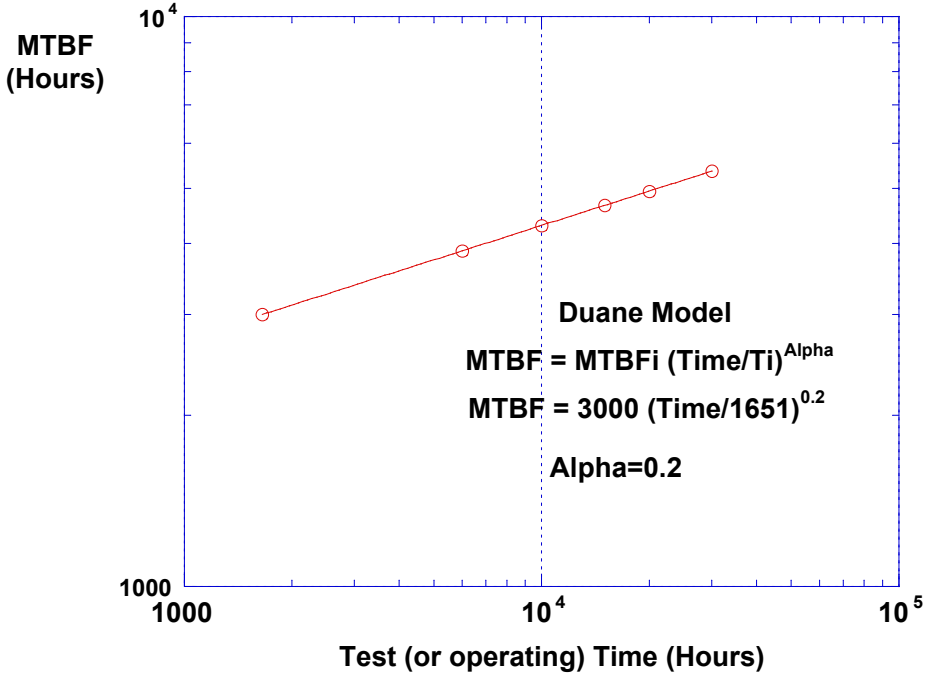
Overview

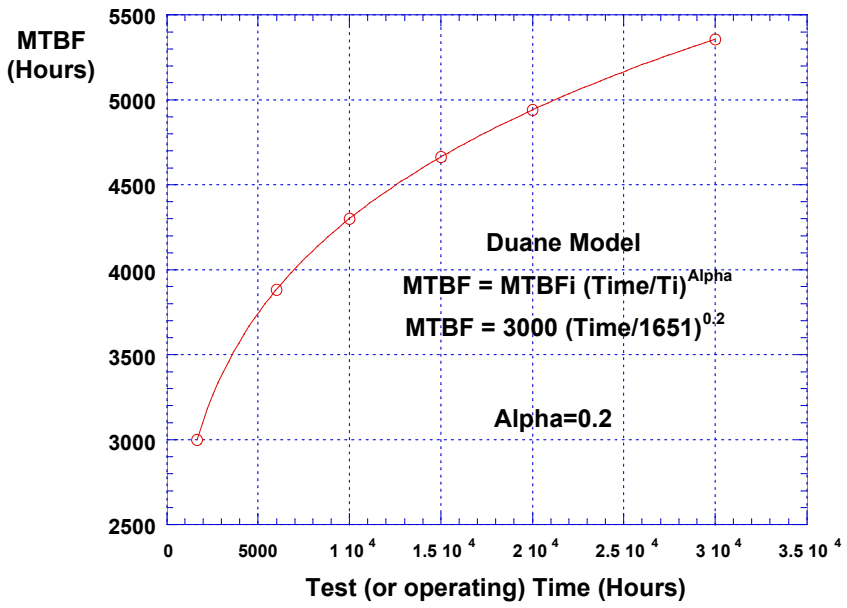
- What is Accelerated Reliability Growth?
- Fix Effectiveness Estimation
- Importance of Estimating Reliability Growth
- Key Strengths of CARG
- CARG Model
  - Case of a Single Accelerated Stress Test
  - Case for a Single Accelerated Stress Type and Multiple Tests
  - Case for Multiple Accelerated Stress Types and Multiple Tests
- CARG Application Example
- CARG Planning Model
- Conclusion

Background - Duane Reliability Growth Model

- Duane obtained a straight line on a log - log plot of MTBF versus operating time

$\text{Log}(MTBF)=\log(MTBFi)+\alpha \log(T/Ti)$ or $MTBF=MTBFi\,(T/Ti)^{\alpha}$





Duane, J.T., "Learning Curve Approach To Reliability Monitoring," IEEE Transactions on Aerospace, Vol. 2, pp. 563-566, 1964.

Reliability Growth Test/Fix

- Duane theory - newly introduced systems have a time to maturity based on the alpha slope.
  - α=0.1 Little effort put into reliability and quality
  - α=0.6 Ambitious effort to improve quality reliability
- Test Analyze and Fix (TAAF)
  - Cornerstone of reliability growth
  - Alternative towards field demonstration testing
- Accelerated testing
  - Improves the growth over time

Accelerated Reliability Growth Concept

- To improve (Grow) Reliability
  - Find and fix failure modes
    - "Finding Failures is GOOD thing - creates opportunity for design improvement"
- To find a hidden failure mode
  - Stress it
- To accelerate this process
  - Raise stress level

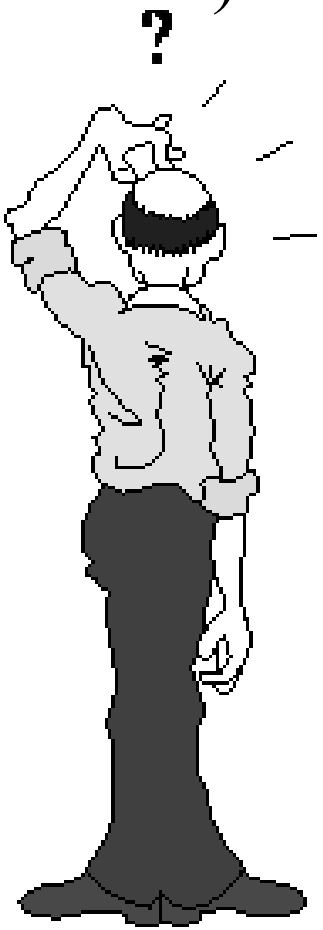
Estimating Fix Effectiveness

- Two kinds of Failure Modes
  - A Modes - Fixes cannot be assigned
  - B Modes - Fixes can be assigned
- Generally 95% of the potential failure modes can be assigned
  - Corrective actions
- Fix Effectiveness factor is about 70%
  - Products can be improved by about 66.5% (=0.95 x 70%). Fix effectiveness factor f=0.665
  - Yields a factor of 3 improvement… typical in TAAF
- When Retest fix verification is done f=1 (if testing is conclusive)

Why & How Do I Quantify Reliability Growth

- Justify expensive reliability testing
- Provide failure rate estimates with new fixes in place
- "What if" estimates (how do fixes effect the AFR)
- What is my test growth achieved?
- What is my growth for
  all tests combined with the fixes?
  - What about acceleration factors?
  - Confidence Level?

- CARG provides these estimates



Duane or Crow/AMSAA shortcomings

- Growth assessment to a zero failure test result is problematic for the models
- Statistical significance is not intrinsic in the basic models
- The models don't not lend themselves easily to multi-growth test analysis
  - CARG overcomes these issues quite easily

Key Accelerated Tests

HIGH TEMP. OP LIFE
Intermetallics, Diffusion, Elec. Overstress...

TEMPERATURE CYCLE
Thermal Mechanical - Connections, Materials...

VIBRATION
Assembly structure, Resonances, SMT...

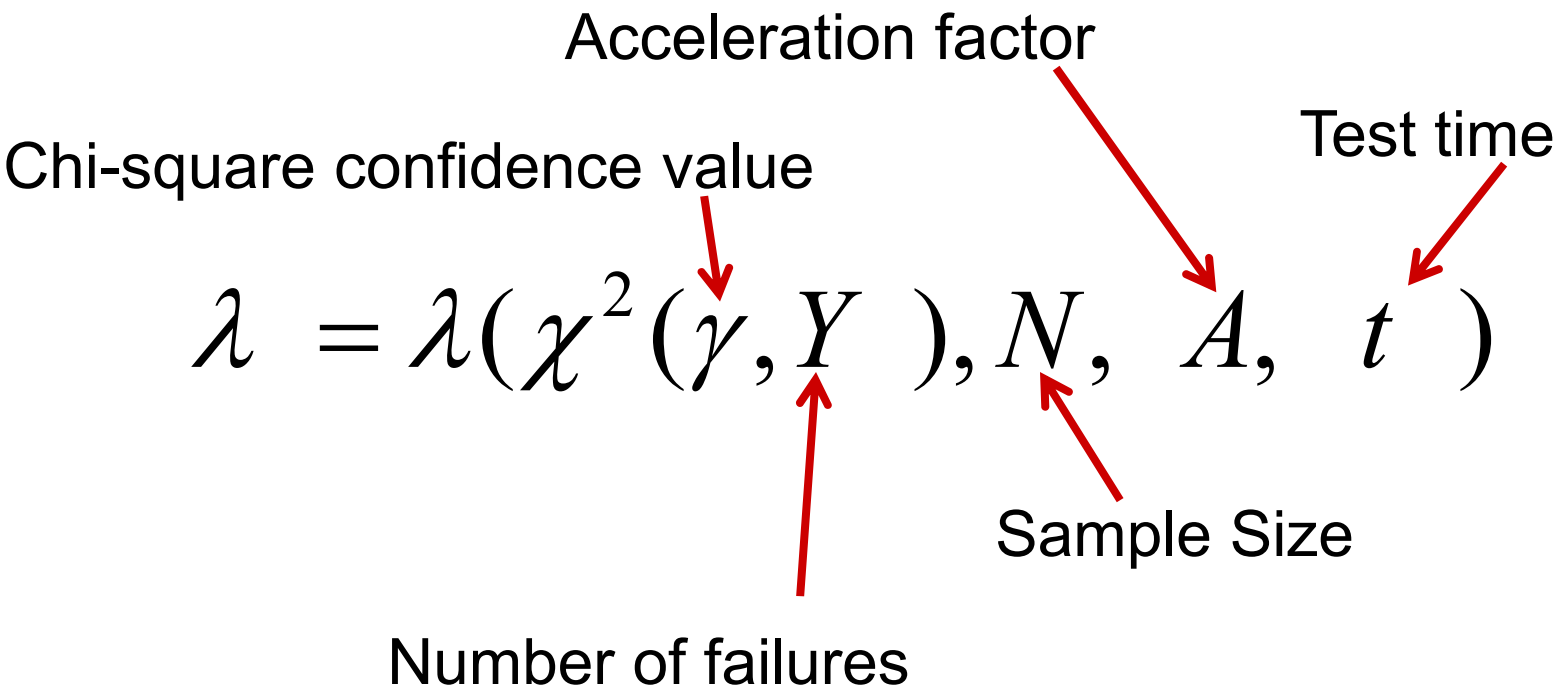
(Mainly Assemblies)

Temp-Humidity-Bias
Process related Corrosion, Dendrite Growth, Leakage Current...

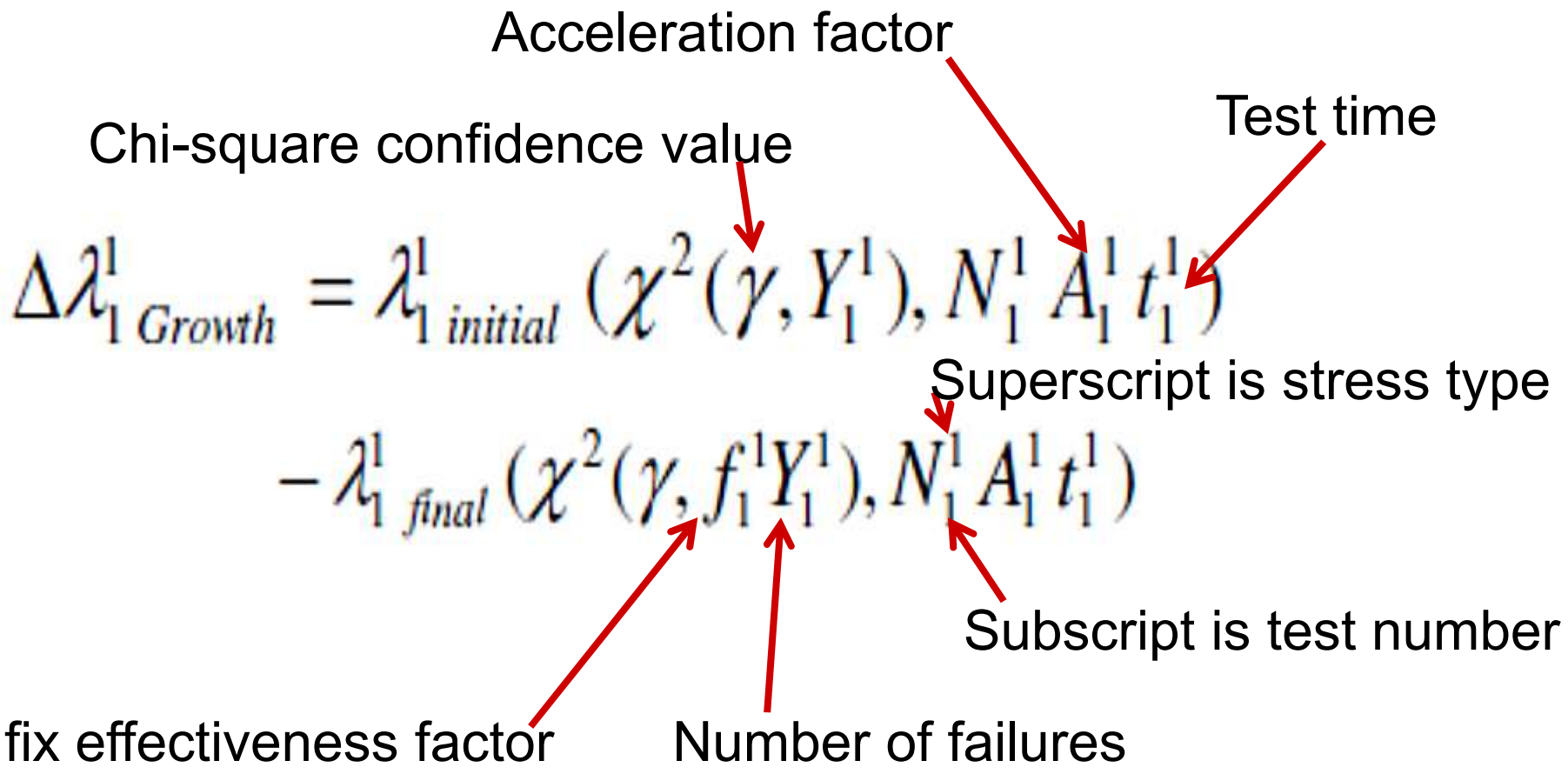
HASS
< 10% Life Verification
Based on HALT Input

(Mainly Assemblies)

CARG Model


Acceleration factor
Chi-square confidence value
Test time
$\lambda = \lambda(\chi^2(\gamma, Y), N, A, t)$
Sample Size
Number of failures

Case for a Single Accelerated Stress Test



Case of a Single Accelerated Stress Type and Multiple Tests

- Multiple T tests groups, same stress type S=1

Same stress type S=1

$$\Delta\lambda^1_{StressT\ Growth} = \lambda^1_{Iinitial}\left(\chi^2(\gamma, \sum_{T=1}^{n} Y_T^1), \sum_{T=1}^{n} N_T^1 A_T^1 t_T^1\right)$$

$$- \lambda^1_{Final}\left(\chi^2(\gamma, \sum_{T=1}^{n} f_T^1 Y_T^1), \sum_{T=1}^{n} N_T^1 A_T^1 t_T^1\right)$$

Subscript is test number

Case of Multiple Accelerated Stress Types and Multiple Tests

- Multiple T tests groups and a number of different types of accelerated S stress tests, the total reliability growth achieved is

stress type

$$\Delta\lambda^{All}_{Stress\ Growth} = \sum_{S=1}^{K} \lambda^{S}_{Initial} - \sum_{S=1}^{K} \lambda^{S}_{Final}$$

Duane type of growth parameter

- Two points on a growth plot – Initial and final failure rates for
  - Each accelerated stress test
  - Total growth achieved for all tests
- A growth parameter can be found from the plot

$$\lambda \propto t^{\beta-1}$$

  - β-1 obtained from slope of the log-log plot over the test time. The growth Alpha= β-1

CARG Example for Electronic Assembly Humidity test Inputs and Results

Humidity Test	Sample Size	Test Time	Accel. Factor	Num. Fail Test	Fix Effec. Factor (%)
Humidity Group 1	30	100	55	0	75
Humidity Group 2	20	100	55	2	75
Humidity Group 3	25	100	55	0	75
Humidity Group 4	40	100	55	0	75
Humidity Test Summary	115	400	55	2	75

CARG Example for Electronic Assembly Temperature Shock test Inputs and Results

Temperature Shock	Sample Size	Test Time	Accel. Factor	Num. Fail	Fix Effec. %
Temp Shock Group 1	22	240	13	0	75
Temp Shock Group 2	35	240	13	1	75
Temp Shock Group 3	22	240	13	1	75
Temp Shock Group 4	30	240	13	1	75
Temperature Shock Test Summary	109	960	13	3	75

CARG Example for Electronic Assembly Vibration Test Inputs and Results

Vibration	Sample Size	Test Time	Accel. Factor	Num. Fail	Fix Effec. %
Test Group 1	70	18	1460	3	75
Test Group 2	65	18	1460	3	75
Test Group 3	60	18	1460	4	75
Test Group 4	100	18	1460	5	75
Vibration Test Summary	295	72	1460	15	75

CARG Example Summary

	Total Samples	Total Test Time	Total Fail	Avg. Fix Effec-tivenes s
All Test Summary	519	1432 Hrs	20	75%

Chi Squared Accelerated Reliability Growth (CARG) in DfRSoft

Confidence All Tests	ENTER
Chi-Square Conf.	Confidence %
	60

DIRECTIONS:

RELIABILITY GRO

Hyperlink to All Test Rel Growth Graph Resul

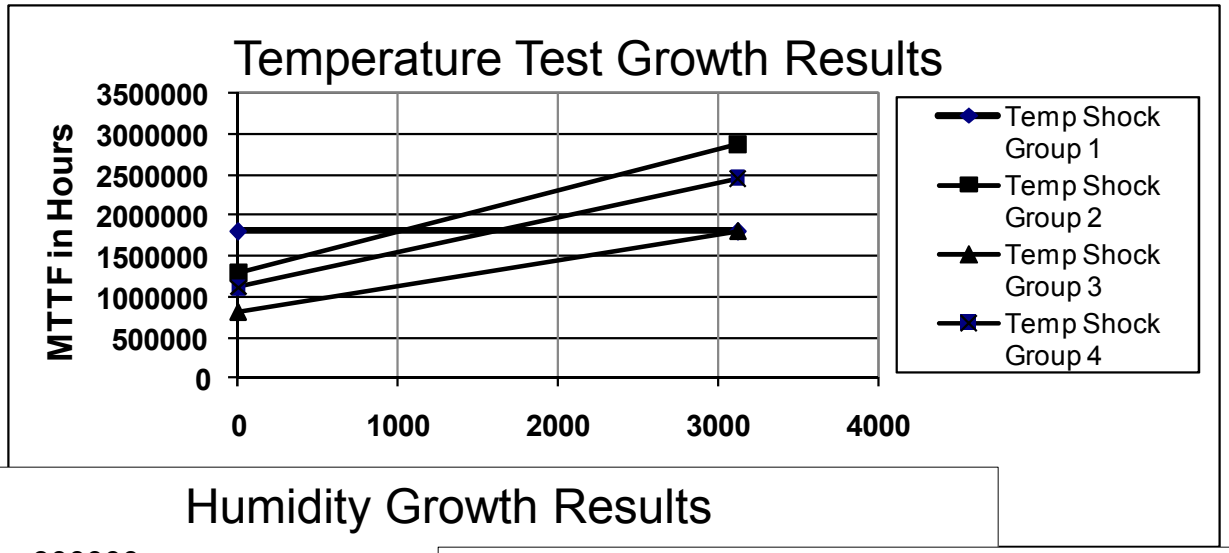
Hyperlink to Individual Test Rel Growth Grap

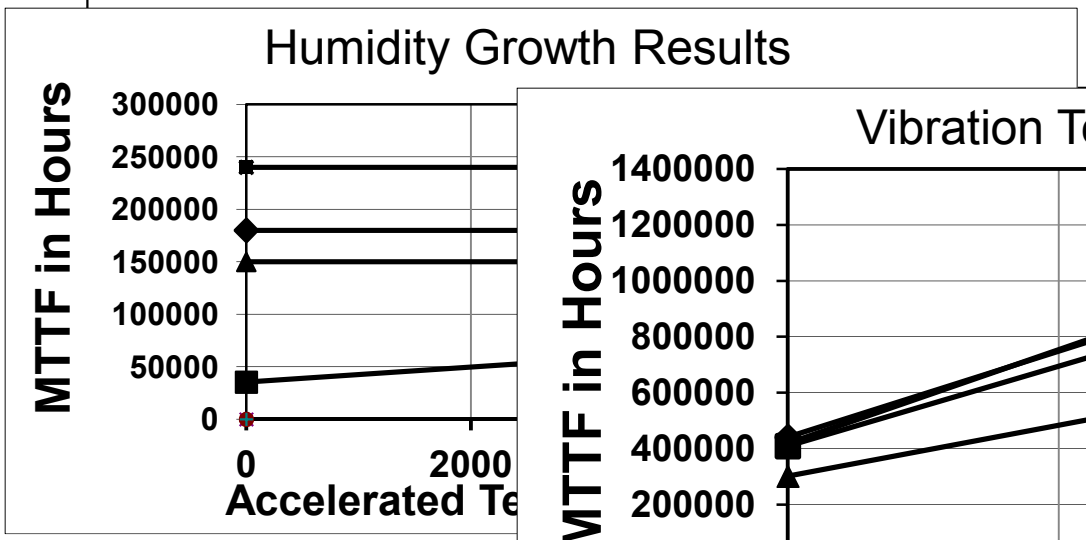
Enter Test Titles Humidity Test	Sample Size	Test Time	Accel Factor	Number Fail Test	Fix Effec. Factor (%)
Humidity Test Group 1	30	100	55	0	75
Humidity Test Group 2	20	100	55	2	75
Humidity Test Group 3	25	100	55	0	75
Humidity Test Group 4	40	100	55	0	75
Humidity Test Test Summary	115	400	55	2	75
Temperature Shock	Sample Size	Test Time	AF	Number Fail	Fix Effec. %
Temp Shock Group 1	5	240	13	1	75
Temp Shock Group 2	5	240	13	1	75
Temp Shock Group 3	4	240	13	1	75
Temp Shock Group 4	3	240	13	1	75
Temperature Shock Test Summary	17	960	13	4	75
Vibration	Sample Size	Test Time	AF	Number Fail	Fix Effec. %
Test Group 1	70	18	1460	3	75
Test Group 2	65	18	1460	3	75
Test Group 3	60	18	1460	4	75
Test Group 4	100	18	1460	5	75
Vibration Test Summary	295	72	1460	15	75
	Total Samples			Total Fail	Avg. Fix Eff %
All Test Summary	427	1432		21	75

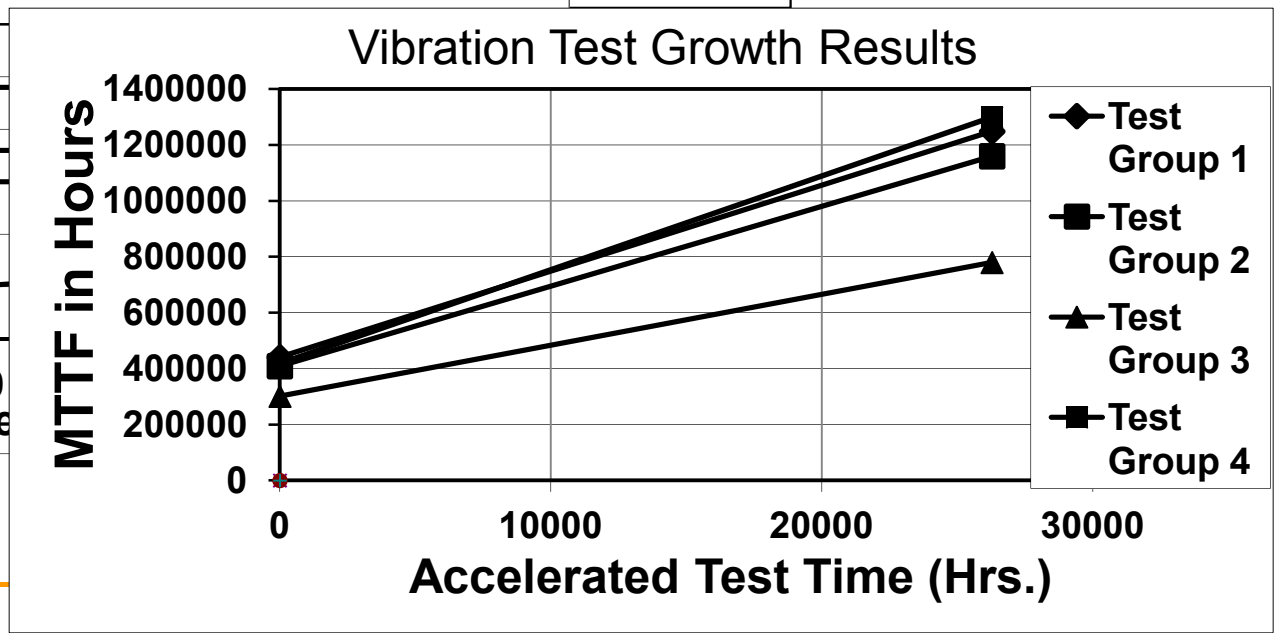
The Advantage of CARG

- Uses a fix effectiveness estimation factor
  - Often we do not have time to retest the fix that was implemented
  - Allows us to estimate the growth with the fix
  - Is the only reliability growth method for Multi-test capability that can effectively incorporate acceleration factors and fix effectiveness

CARG Test Results







Summary of Growth Alphas

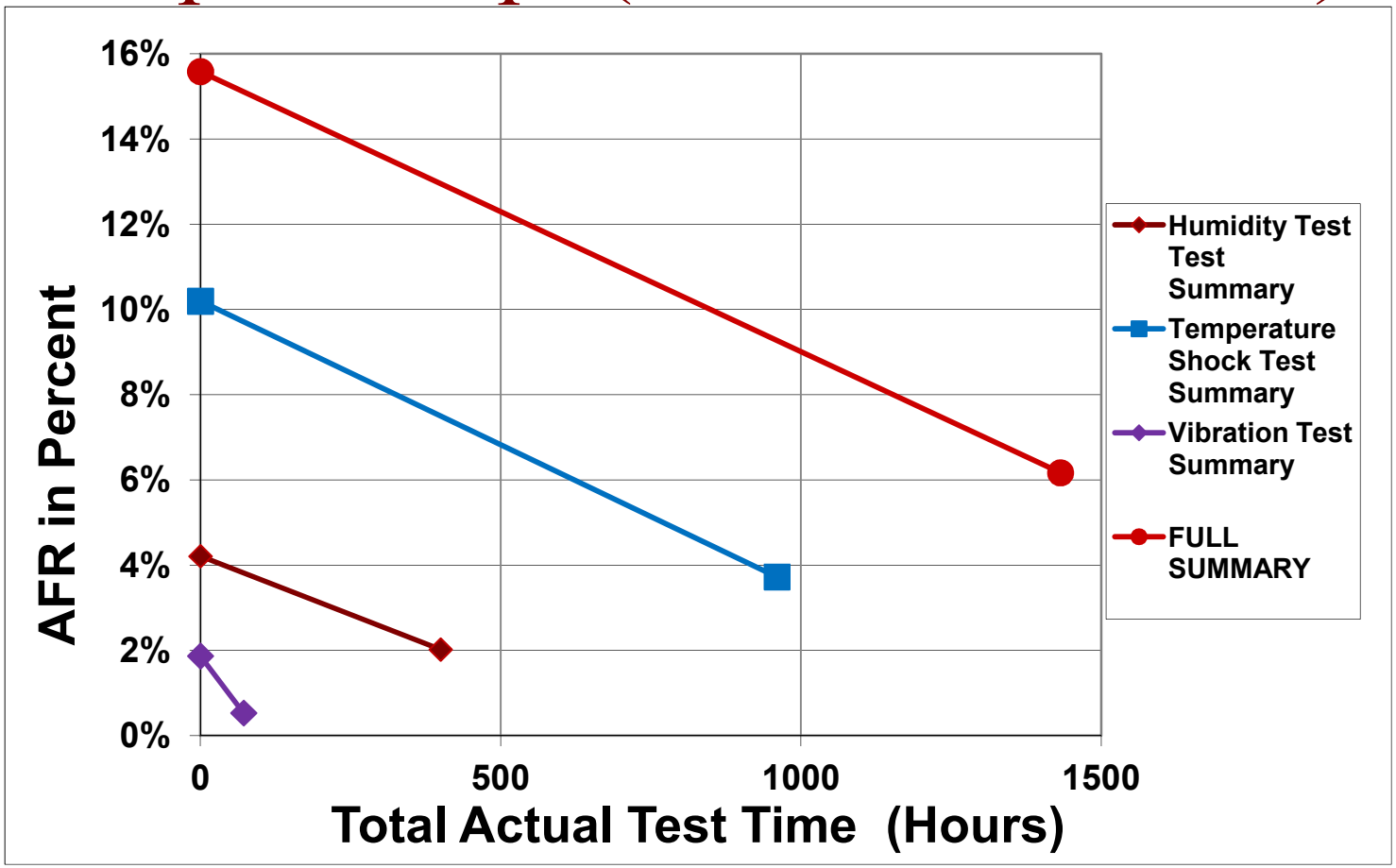
All Tests Reliability Growth Summary and Reliability Growth Beta Metric			
		Alpha=1-Beta	0.130110266
	Initial and Final	Beta	0.869889734
Total Test Hours	MTTF Results	Ln(Cum Time)	Ln(MTTF)
1	9476.367511	0	9.156556348
1432	24392.84631	7.266827348	10.10204518

Humidity Test Summary			
		Alpha=1-Beta	0.124473421
	Initial and Final	Beta	0.875526579
Total Test Hours	MTTF Results	Ln(Cum Time)	Ln(MTTF)
1	203678.8688	0	12.22429986
400	429371.5686	5.991464547	12.97007795

Temperature Shock Test Summary			
		Alpha=1-Beta	0.13855295
	Initial and Final	Beta	0.86144705
Total Hours	MTTF Results	Ln(Cum Time)	Ln(MTTF)
1	10128.67443	0	9.223125733
960	26227.39089	6.866933284	10.1745596

Vibration Test Summary			
		Alpha=1-Beta	0.293103981
	Initial and Final	Beta	0.706896019
Total Test Hours	MTTF Results	Ln(Cum Time)	Ln(MTTF)
1	530117.3502	0	13.18085362
72	1856793.331	4.276666119	14.43436154

CARG Results for Multiple Tests with Multiple Groups (60% Conf. Results)



Note: AFR=1-Exp(-8760/MTTF)

CARG Growth Testing Estimates

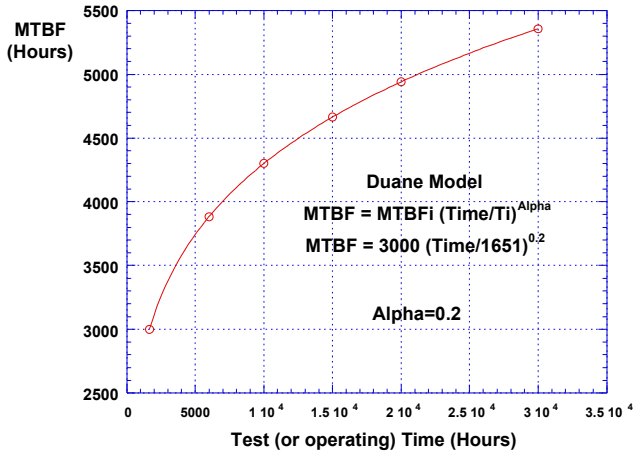
Test	CL	Initial AFR	Final AFR	Growth %	Growth Alpha
All Tests Combined	60%	15.6%	6.0%	60.3% 2.6 factor	0.134
	90%	23.7%	12.4%	47.7%	0.098
Humidity Test	60%	4.2%	2.0%	52.4%	0.124
	90%	7.1%	4.2%	40.8%	0.089
Temperature Shock	60%	10.2%	3.7%	63.7%	0.152
	90%	15.8%	7.7%	51.3%	0.11
Vibration	60%	1.9%	0.5%	73.7%	0.296
	90%	2.4%	0.83%	65.4%	0.25

CARG Warrantee Cost Saving per 1000 units

Conf.	Unit Cost	Initial AFR	No Growth Warr-antee Loss Per 1000	Final AFR	Growth Warr-antee Loss Per 1000	Savings Per 1000
60%	$35	15.6%	$5,469	6.2%	$2,170	$3,299
90%	$35	23.7%	$8,295	12.4%	$4,340	$3,955

CARG Planning Model

$$\lambda_F = \lambda_I \, t^{\beta-1}$$



$$\lambda_I = \lambda_{initial}\left(\chi^2(\gamma, Y\ ), N\ \ A\ \ t\ \ \right)$$

- Use Duane with modification for initial failure rate

CARG Conclusions

- A new model has been developed called CARG
- It offers a new way to estimate reliability growth for industry in the popular area of chi-squared accelerated testing
- It is the only reliability growth method that easily lends itself to multi-stress tests situation
- It can handle growth to zero failures
- Confidence is intrinsic to the model
- Uses fix effectiveness factors so that test verification is not required for estimates