# Round-Robin, Predictor Models for T-Cycle life

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**Abstract**
Solder joints tend to crack after extended thermal cycling, if the component and the circuit board are CTE mis-matched. Predicting t-cycle lifetime is a crucial first step in optimizing product design and/or in-service conditions. Predictor models embody cyclic fatigue physics and math, and require inputs of the materials and geometry of the hardware as well as the thermal conditions of the environment. The output is the predicted number of t-cycles to fail (i.e. to develop electrical-open cracks thru the solder-fillet). Several predictor models are in use within the industry. This paper describes a comparison among several predictor models, rating them for ease of use, and for accuracy against known actual test results and against each other. The study uses a round-robin approach; wherein each participant was given the same input data for ten different components, but the actuals were withheld until the respective predictor results were in. Also, this paper describes a related study on the ability of each model to perform parametric analyses: i.e. to define the effect of variations in hardware and environmental conditions on t-cycle life. The results offer guidance on t-cycle life prediction, as well as on improving t-cycle life

**Introduction**
Any solder joint will crack sooner or later, over time, if construction elements have different CTEs (coefficient of thermal expansion), and if the solder joint experiences thermal cycling (i.e. cycling from a higher to a lower temperature and back) in service. Prediction of life, for each new product design and application deployment, is crucial. Designers of the hardware and applications engineers strive to deploy the most robust hardware and to provide the most benign in-service conditions possible. Other factors inevitably are in conflict; cost, operational duty cycles, applications conditions and thermal management restrictions, density and mass, and the press of new packaging technologies. The struggle never ends; the consequences are severe: loss of market or profit when solutions are too conservative, loss of business or worse, if failures occur in-service, when deployment is ill-considered.

Prediction is considered an art: the territory of specialized consultants and/or arcane physics and math. This utilization of outside expertise is an expensive, lengthy, and often necessary process. In other cases, designers arrive at a “prediction” or a feel-good by apparent similarity or default, often incorrectly or conservatively. The desire of all designers should be to predict t-cycle life, with reasonable accuracy, from knowledge of the solder-joint and the t-cycling conditions.

The-cycle failure discussed here is the “legitimate”, background, failure mode: cyclic fatigue through thru the solder fillet, responding to laws of physics. Other premature electrical failures can arise that are caused by a wide variety of problems (circuit board plating, contamination, workmanship errors, etc; and are often not analyzed for root cause, and therefore can be lumped in with “legitimate” solder-joint failures. This confusion factor is a very real situation: all effort must be made to control workmanship and point defects, but these cannot enter into prediction physics. No predictor model can anticipate and predict the life consequence of a non-wetted land or a trapped fragment of label-stock under a joint. Therefore all discussions in this study apply to nominal, well-characterized IPC 610 class3 solder-joints. Second-order die-shadow effects were not studied, in either predictions or actuals; only far-diagonal points were considered.

Note that this prediction exercise completely sidesteps the effect of vibration and shock. It is known that damage initiated early-on by vibe/shock will foreshorten t-cycle life; and conversely that t-cycle damage will weaken a joint against shock; but all that was not included in this study, in the actuals as well as in the predictions. Similarly, the Grid Array specimens were not under-filled, so any models’ ability to predict that effect was un-explored. Effects of board-warp, typically arising in assemblies of rigid components on thin substrates, also were not explored.

Note further that this discussion centers on the familiar Sn63 tin-lead solder joint. This system is well characterized; materials properties are known and empirical experience and modeling and data-bases are extensive. In addition, circuit-board finishes, as well as assembly workmanship, have evolved well enough to push extraneous failure modes into the background, leaving only the fundamental cyclic fatigue crack growth model as the operant model. In contrast, as of this writing, the lead-free situation is still rapidly evolving ... alloy selections are being explored and hopefully converging, PWB platings and compatibilities are being finessed, workmanship attributes and thresholds are being documented, and empirical data-bases are growing. This Round-Robin does not cover any lead-free situation, but should serve as an example of how to compare and select models, as they come into use across the industry. Accurate prediction with confidence is the goal. Absent that, decisions are typically made with extreme conservatism, to be safe, to the detriment of new-product application opportunity. Lead-free designers will need this confidence.

### Round Robin Ground-Rules

This round robin follows the classic format (Figure 1), in that all the participants receive the same instructions and the same solder-joint geometry and materials information.

**CLASSIC ROUND-ROBIN**

SEVERAL LABS, TRYING TO COMPARE / CALIBRATE THEIR INSTRUMENTS.

GIVE THEM ALL IDENTICAL SAMPLES OF UNKNOWN COMPOUND.

WITHHOLD THE ÒACTUALÓ OR ÒSTANDARDÓ ANALYSIS VALUE.

EACH LAB DOES ITS ANALYSIS, AND REPORTS THEIR RESULT.

GIVE ALL LABS THE ÒACTUALsÓ, AND SHARE OTHER LABS Õ RESULTS.

**THE PREDICTOR MODEL ROUND-ROBIN**

SEVERAL PARTICIPANTS, EACH WITH HIS OWN PREDICTOR MODEL.

GIVE EACH PARTICIPANT A SET OF FACTS (MATERIAL AND GEOMETRY AND TEST CONDITIONS) ON TEN DIFFERENT PACKAGES/SOLDER-JOINTS.

WITHHOLD ACTUAL T-CYCLE TEST RESULTS ON THESE TEN SPECIMENS.

EACH PARTICIPANT CALCULATES HIS T-CYCLE LIFE PREDICTIONS.

REPORT ALL RESULTS: COMPARISONS VS ACTUALS, AND EASE-OF-USE.

FIG 1

They also all receive the same set of environmental conditions, in this case –10 to +125 C, with 30-minute ramps and dwells. Their task is to predict the life of the solder-joint, under those conditions. To simplify the experimental work as well as the predictor modeling, the prediction was to be at F50 (number of cycles at which half of the specimens had failed). The F63 could have been used, but the author likes round numbers, and F50 is as easy to deduce as is the Weibull eta. Also, the instructions included the possibility that certain of the models were configured to “need” additional information. This was supplied to the participant, on request, insofar as possible. Additionally, the participants were encouraged to describe, subjectively, their impressions of “ease-of use”, which was conveyed to the author, and is summarized below.

Note that in every case, the PWB was polyimide/glass 20 layer, constructed with a representative layup of trace and ground planes; resulting in a with a measured X-Y-axis CTE, weighted over the profile span, of 17.5 ppm/C. “Failure” was defined as progress of a crack thru 90% of the area of the solder-joint fillet at the empirical fracture plane. This metric is difficult to establish, certainly: the reported actuals were established thru separate studies involving sequenced cross-sectioning, and fracture-surface inspections. Fraught with uncertainty as this is (perhaps 25% off in either direction), it’s a specific fracture state that can be described and should make sense to a physics-based model; plus it’s much better than predicting a “crack” (these start long before an electrical failure) or an “open”.

### Models and Participants

Several experienced SMT reliability practitioners, each using their respective favorite models, volunteered to participate. Some participants entered two models’ results. The participants included five from various mil-aero firms and sites, as well as one worker at a prominent national defense lab, wielding two of his in-house developed models. Three of the entries were based loosely on Engelmaiers work, two utilized Clech’s SRS software, one was from CALCE, and the last two were in-house models developed by a major defense lab. Note that industry experts Werner Engelmaier, Jean-Paul Clech, and Reza Ghaffarian chose not to participate directly, but offered their encouragement to efforts within the industry that would increase awareness and appreciation of SMT t-cycle life prediction issues.

### Specimens

This exercise involved ten components, spanning a healthy range of common shapes and sizes. Components were mounted on a specially-designed test vehicle, using conventional IPC 600 / 610 class 3 processes. Sample size in this testing program was ~ 20 specimens each. These were t–cycled, under periodic and/or continuous inspection for cracking, under carefully-controlled conditions. The resulting actual failure data was analyzed and graphed using Reliasoft software, from which the basic metrics (most usefully the F50) were obtained. These test metrics were withheld from all participants, until all their results were in. See Table 1 for a summary of the components / solder-joints.

| # | description | Details of Components É. Predictor Model Round Robin Table 1<br>dimensional details (dims in mils) | CTE (1) |
|---|---|---|---|
| -0- | circuit board | 135 thick 20-layer polyimide / glass | 17.5 |
| 1 | 0402 SMR | 19X39, 9caps, 29X35 lands, 28X35 foot, 24X30 fracture plane, fillet to cap, 1.2 mil sldr thick, 21 toe. | 6.4 |
| 2 | 2010 SMR | 99X196X 21, 20 caps, 65X121 lands, 51X110 foot, 40 X115 fracture plane, 1.1 mil solder film, 9 toe. | 6.4 |
| 3 | 52 I/O LCCC | 750X750 , 950 cas diag, 25 cas-land w idth, 34x96 lands, fillet3/4up .85 solder, 36 toe | 7.5 |
| 4 | little Plastic FP 28 I/O 50 pitch | 273X774X90, 490landtoe-toe, 655 body-attach diagonal, 715 foot-center diagonal, 10X16 leads, 35X121lands, 75 degree angle,15 radius, 28 straight lead-length, 11shoulder, 11X40 foot, 30X94 w etted foot, 28x55 fracture plane, toe fillet to top of lead, heel fillet 23 up heel, 23 heel fillet , 23 toe fillet, 0.9 mil sldr film thick | 14.0 |
| 5 | big Plastic QFP 144 I/O 25 pitch | 1089X1089X140 body, 1320X1320 land toe-toe, 1382 body-attach diag, 1490 foot diagonal, 6X11 leads, 18X120 lands, 80 angle, 20 radius, 60 straight l-l, 15 shoulder, 10X38 foot, 18X93 foot, 11x50 fracture plane, toe filletto top, heel fillet, 15 up heel, 20 heel fillet length, 38 toe fillet length, .8 mil sldr thick | 14.0 |
| 6 | little ceramic FP 28 I/O 50 pitch | 393X720X90 body, 696 landtoe-toe, 720 bodydiag, 875 foot diag, 5X17leads, 35X12lands, 70 angle, 21 radius, 30 straight lead-length, 23 shoulder, 17X44 foot, 35X90 w etted foot, 25x50 fracture plane, toe fillet to top, heel fillet18 up, 30 heellength, 35 toe length, .8 mil sldr thick | 7.5 |
| 7 | Big ceramic QFP 192 I/O 25 pitch | 950X950X94 body, 1495X1495 landtoe-toe, 1521 bodydiag, 1740 foot- diag, 4.5X6leads, 20X120 lands, 85angle, 20 radius, 80 straight lead-length, 40 shoulder, 6X45 foot, 15X80 w etted , 6.6x13 fracture plane, toe fillet to top, heel 15 up, 33 heel length, 36 toe length, .8 mil sldr thick | 7.5 |
| 8 | Big P-BGA, Amkor 1517, 1mm | 1572 sq body, 2068 ball diag, 16 collaps ht, 28 fattest, 25at fracture plane, 20.5 dia land NSMD on PWB, 22.5 land slite SMD on package, | 15.0 |
| 9 | Big C-BGA 625 full, 1.0mm | 1281 sq body, 1692 ball diag, 36 assembled ht, 35 dia fattest part, 29 dia at fracture plane, 37 dia land NSMD on PWB, 35 land on package, 1 mil thinnest film, fillet covers land and 8 mils up ball sides, 75% fails at bottom fillet. | 5.3 |
| 10 | Big Ceramic ColGA, 625, 1.27mm | 1281sq body, 1692 ball diag, Raychemcolumns, 88 ht, 21coldia, 29 dia at f plane, 37land NSMD on PWB, 35 land on package, 1 mil film base, fillet 10 up column sides, and dow n 5 mils from package, 75% fails at bottom fillet. | 5.3 |
| | (1) CTE (w eighted average from -10 to + 125). | | |

Note that the components were not selected necessarily to make it easy for the participants. It was understood, going in, that some models might be able to cope with BGAs, or columns, some couldn't. Participants were encouraged to use whatever available finesse they could justify, in tweaking their models beyond the models' nominal capability.

**Results**

As expected, all models agreed on the obvious. The notoriously fragile components (the LCCC and the big Ceramic BGA) failed soonest by actual test; and were in fact predicted to fail soonest, by all the models, Similarly, the more robust packages .the 0402 and the small plastic gull-wing ... took forever to fail, as expected, and all predictions agreed on that. However, also as expected, disagreements and crossovers were plentiful, within the predictive results. This fact, the inability of predictor models to predict correctly, is unfortunate, but has been acknowledged by the industry, See Table 2 for a summary of actual test results and the corresponding predictions.component the actual test value is within the range of predicted values. The actuals fell near the center of the predictions in almost every case. Some predictions were "high"; some were "low", relative to the actual. The one exception was component # 8, the big plastic BGA. The "actual" value was less than any of the predictions: it failed "too soon". The reason, suggested by Reza Ghaffarian and confirmed thru destruct failure analysis, lies in its premature failure artifact. Most of these specimens had failed not thru the solder fillet waist, but had popped loose at the package interface: a bad plating situation, not governed by any predictor model rationale. An educated guess at a proper F50 would have put the 'actual" in the middle of the prediction spectrum, like all the other components.

| ROUND ROBIN ÉÉÉÉ PREDICTOR MODEL TABLE 2 SUMMARY | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | COMPONENTS / DESCRIPTIONS (see Details). AND PREDICTED F50s | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| PREDICTOR MODELS | 0402 SMR | 2010 SMR | 52 I/O LCCC | 28 I/O P-FP | 144 I/0 C-QFP | 28 I/0 C-FP | 192 I/O C QFP | big P-BGA | big C-BGA | big CCol-GA |
| Cliff (Engel) 100% | 1844 | 25 | 1 | 20 | 541 | 63 | 607 | 2819 | 0.2 | 6469 |
| Cliff (Engel w 'correct' solder) 100% | 15380 | 256 | 13 | 332 | 11540 | 1349 | 12960 | na | 26 | na |
| D (Clech) | 1728 | 2646 | 762 | 29320 | 40,140 | 38840 | 14400 | 963 | 244 | 6228 |
| B (Engel) | 31981 | 632 | 37 | 209 | 85814 | 5669 | 132560 | | | |
| G (CALCE) | 33025 | 811 | 431 | 29215 | 130000 | 4611 | 3019 | 1451 | 961 | 1294 |
| K (Engel) | 1844 | 25 | 1 | 869 | 60621 | 1086 | 166 | 7066 | 175 | 1482 |
| K (Clech) | 4325 | 9078 | | 79110 | 21790 | 49030 | 3164 | | | |
| N (SIP) | 2237 | 502 | 119 | 1361 | 2258 | 944 | 792 | 2059 | 1089 | 1328 |
| N (CM) | 1667 | 82 | 310 | 561 | 2631 | 330 | 1844 | 1365 | 271 | 441 |
| ACTUAL TEST RESULTS | | | | | | | | | | |
| Cracks begin, (est) | 2500 | 300 | 75 | 1500 | 1400 | 1000 | 1200 | 250 | 50 | 500 |
| Cracks at 50% thru fracture plane area (est) | 8000 | 900 | 360 | 4800 | 3800 | 3600 | 3700 | 400 | 60 | 2500 |
| Cracks at 100% thru fracture plane area (est) | 10000 | 5200 | 500 | 5600 | 5000 | 4000 | 4600 | 550 | 75 | 3225 |

**Figures 2 thru 11 show graphically how the predictions varied, for all the components. For almost every**

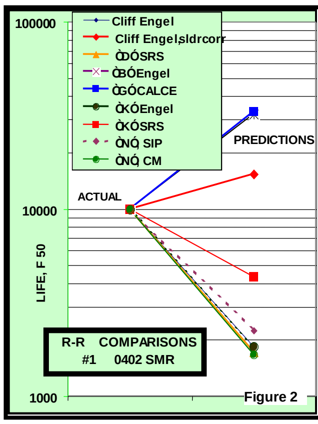

Figure 2

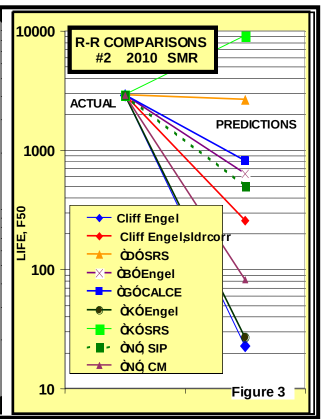

Figure 3

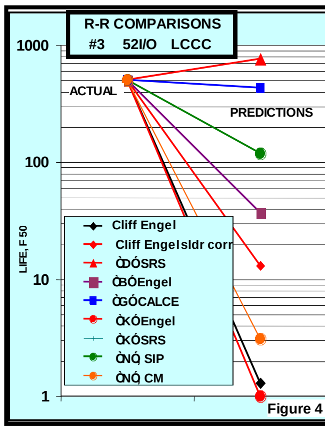

Figure 4

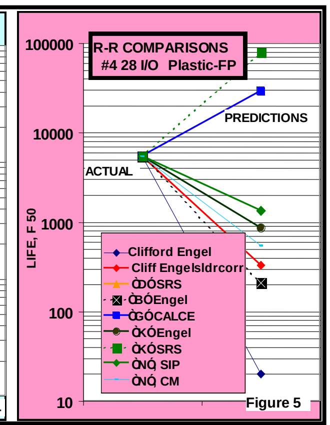

Figure 5

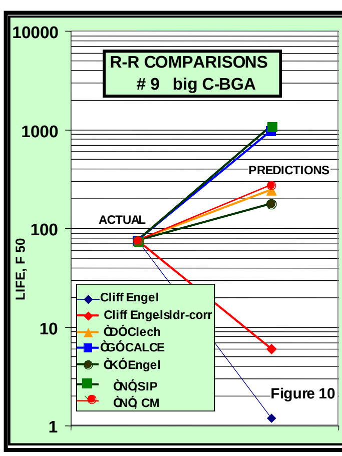

Figure 10

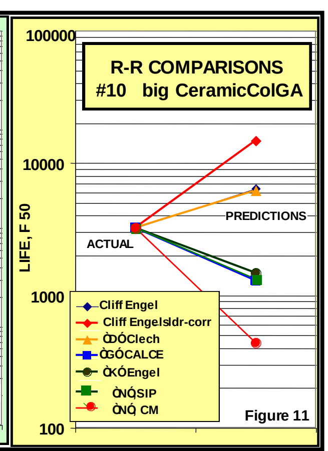

Figure 11

Note that there is no clear systematicity in the predictions. The various models did not all line up nicely. Some predicted high for some components, some predicted low. This was no surprise given the difficulty in accommodating the various GUI input requirements and the definition-of-failure structure of each model. Also, it was not surprising that the user's contributions overrode the source contribution: each user apparently applied his own finesse and/or used tailored versions of his respective model.

**Ease of Use**

The models ("based on Engelmaier") used by three of the participants are the easiest to use, but that's because these are various versions of a simple 1-page Excel spread-sheet format: simply plug in certain simplified inputs (geometry and materials properties and cycling parameters) and read the predicted life. The physics and math are internal. One-FAT parametric studies are key-stroke easy. The Clech model is more involved but is desk-top capable. The "SIP" model is even more demanding, desk-top and slower, but offers graphics and intermediate information, which might be interesting to some. The N-CM model is proprietary in-house, not available publicly, and involves a main-frame and substantial time and operational skill. Certainly any future successful model should be some sort of PC-based 1-page, plug and play format, with math and default properties hidden within, to be useful to the design community.

**Conclusions from the Round Robin**

One conclusion is that no one prediction, from a blank sheet of paper and a set of "known' inputs, can be counted on the accurately predict the (100% electrically-open) life of a conventional solder-joints under t-cycle conditions, Typically, the error will be a factor of maybe 2-3X, sometimes an order of magnitude, either way. Less often, for some combinations the error can be much greater. Of course, the 'actual" could be questioned, but the error contribution of testing would be in the order of a factor of two; and that would lie in the definition of failure, not in methodology or statistics.

Comparisons among the different models show no clear 'winner". Some fared better with certain components, other models were better for others. The CALCE model, as wielded be "G", seems to be consistently within ~2X. The "Engelmaier-based" model, using typical solder measured thickness, tended to predict consistently very low, but fared better when the recommended arbitrarily thicker solder film was input. Several models were not structured to handle BGAs, non-melt or collapse, nor column-grid-arrays, so the participants had to improvise. Certainly any of these models, and others, could be 'tweaked", by an experienced user, using corrections and calibrations that are empirically based, and that do not violate known physics. This approach probably is essentially some combination of a "from-scratch' model plus a parametric analysis subroutine, as discussed below.

There may be other predictor models in use and other experts that could do a better job than the ones participating in this exercise. They are welcome to try their hand... no fair peeking at the actuals. The author will gladly provide assistance if requested.

## Parametric analyses

**Introduction and Ground Rules**

This exercise is directed to the critical need for accurate predictions, in the face of the expected and recognized absolute from-scratch inaccuracy of a given model and component situation. For critical decisions, designers typically do not rely solely on "from-scratch" predictions. Experienced workers usually start with a known situation that is very close to the desired case, and then ratio that result up or down, depending on the difference(s) between the known case and the desired case. For instance: suppose you have a particular 50-mil-pitch C-QFP that you want to mount on a CTE 13 PWB. If it is known that the same component mounted on a CTE 17 PWB has an F50 of 2245 cycles (in a particular test), you can use that fact to establish the F50 of your new component, without doing any testing. Simply look at a parametric response (the effect of CTE on t-cycle life), in close-analog comparisons, to see how big the life improvement will be. Another case: suppose that a certain hardware configuration is well-known to be just fine in a certain application... never experienced a t-cycle failure. You are looking at a candidate hardware that is identical except it will be 25% (diagonal) bigger body size, and the application involves a delta 14 C rather than the baseline 20 C. Will the new application be OK; i.e. will the t-cycle life be at least as good as baseline?

These questions arise frequently. It's much better to answer them by doing comparative parametric response studies than by relying on absolute prediction modeling, given the state of from-scratch prediction documented above. In fact, many "predictor models" commonly in use are simply these parametric-response ratioing devices, rather than from-scratch predictors. The parametric responses described below are the result of a bonus task given to the round-robin volunteers: once they were up and running, and had the cases set up, they were asked to pick one case, and then vary one element, holding everything else constant. That produces the response. That shows what would happen if the CTE were different, or the delta were different, or the body size were different, etc.  Each participant was given the same instruction, each used his own model. The results are discussed below.  Table 3 shows the input cases as well as the results from each participant.

**TABLE 3   ROUND-ROBIN, PARAMETRIC ANALYSIS   AOVs, response surfaces**

| AOVsÉ . hardware | 1) Use component 2, vary the solder thickness, mils | | | | 2) Use component 8, vary the diagonal dim, | | | | 3) Use component 7, vary the lead thickness @ constant width = .01 | | | | 4) use component 9, vary the component CTE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| parameter value | 0.5 | 2.0 | 5.0 | 20.0 | 0.5 | 1.0 | 2.0 | 3.0 | 3.0 | 5.0 | 8.0 | 10.0 | 3.0 | 6.0 | 9.0 | 12.0 |
| C Engel, | 4 | 100 | 834 | 20680 | 89240 | 16710 | 3238 | 1253 | 2870 | 133 | 13 | 5 | 4336 | 7417 | 14940 | 40920 |
| K Clech | 7691 | 11260 | 16990 | 47070 | 102 | 21 | 8 | 3 | 3612 | 3048 | 2556 | 2345 | | | | |
| B Engel | 107 | 510 | 19350 | 443474 | 102 | 21 | 8 | 3 | 288725 | 132596 | 20036 | 736 | | | | |
| D Clech | 2461 | 2962 | 4326 | 13509 | 5754 | 3168 | 1856 | 716 | 16140 | 13920 | 11770 | 11078 | 186 | 267 | 429 | 853 |
| G CALCE | 164 | 400.0 | 1700.0 | 7534.0 | | | | | 3745.0 | 3019.0 | 1558.0 | 118.0 | 311.0 | 600.0 | 1500.0 | 8000.0 |
| N-CM | 44 | 530 | 2095 | 14282 | 15059 | 8525 | 4029 | 2248 | 1763 | 1264 | 674 | 381 | 216 | 373 | 795 | 2905 |
| N-SIP- | 361 | 1231 | 2469 | 5466 | 5644 | 4614 | 3413 | 2592 | 1787 | 1667 | 1373 | 1101 | 1053 | 1315 | 1805 | 3035 |
| AOVsÉ . conditions | 5) use component 5 ...vary the delta @ Tave=40 | | | | 6) 5, vary the average temp, @delta=120 | | | | 7) 5, vary dwells, minutes | | | | 8) 10, vary F.xxx, @ beta 7 | | | |
| parameter value | 180 | 135 | 50 | 8 | -10 | 20 | 50 | 80 | 5 | 30 | 240 | 1000 | 63.0 | 0.1 | 0.010 | 0.001 |
| C Engel, | 164 | 1126 | 30220 | 558000 | 2035 | 1412 | 1010 | 743 | 912 | 541 | 350 | 302 | 2968 | 1107 | 797 | 543 |
| D Clech | 28480 | 33020 | 123700 | 433000 | 33960 | 35250 | 38860 | 66900 | 42780 | 40140 | 36680 | 35590 | 6228 | 1970 | 1342 | 914 |
| B Engel | | | | | | | | | | | | | | | | |
| K Clech | 15580 | 17760 | Crash | Crash | 17840 | 18690 | 20920 | 36650 | 23220 | 21790 | 20040 | 19450 | | | | |
| G CALCE | 274 | 431.0 | 2488.0 | 92000.0 | | | | | 2408.0 | 811.0 | 114.0 | 26.0 | | | | |
| N- CM | 2593 | 4819 | 33403 | 1E+06 | 8068 | 6860 | 5566 | 3857 | 4753 | 4003 | 3160 | 2438 | | | | |
| N-SIP | 2726 | 5772 | 30579 | 229800 | 43924 | 15701 | 5334 | 1623 | 4063 | 2794 | 1464 | 522 | | | | |

## Results

Parametric analysis is a powerful tool, in identifying important factors in t-cycle life, assuming the predictor model incorporates the appropriate physics and math correctly.  All the models agree on the beneficial effect of increasing the solder film thickness.

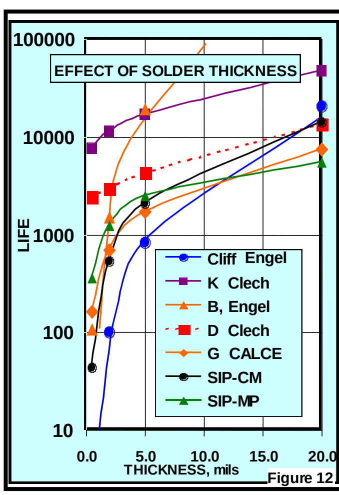

Figure 12

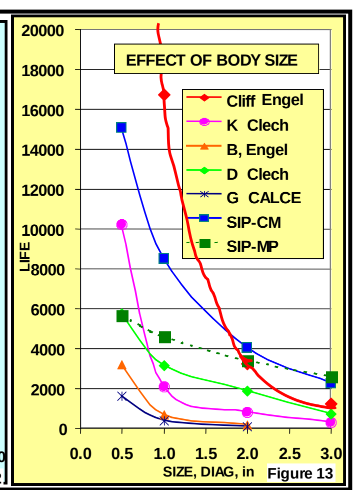

Figure 13

Figure 12 shows an improvement of an order of magnitude, going from 1 to 3 mils thick, and another 10X going from 3 up to 12 mils thick, at least theoretically. Doing that in practice would be a physical challenge; and possibly optimistic. Improvements of only ~2x have been observed experimentally, over that range. Figure 13 shows agreement on the expected reduction of t-cycle life with increasing body size,.  The models show asymptotic reduction: ~1/3 life from 0,5" to 1", then ~1/2 again from 1" to 2" diagonal.  This is consistent with experimental results.

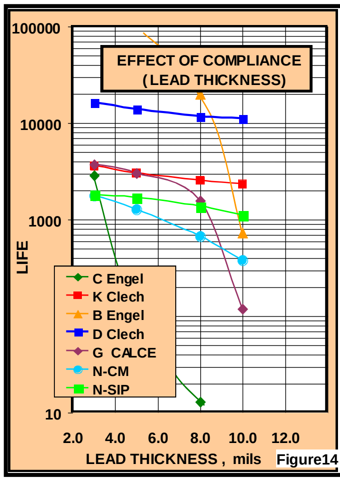

Figure14

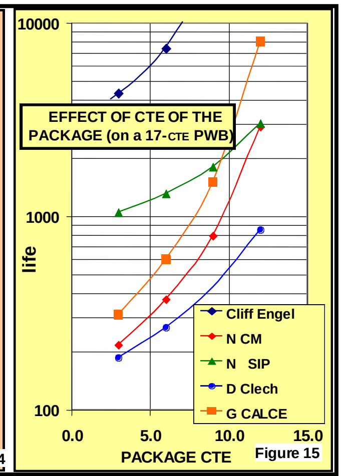

Figure 15

Figure 14 shows only general agreement on the beneficial effect of a more compliant lead, but the results are probably compromised by the different models' input requirements and inadequacy of geometrical information supplied to the participants. Figure 15 shows very good agreement on global CTE mismatch, over these ranges. The projected life will improve 3-5X, going from a CTE 5 package to a CTE12 package, for instance. Certainly this little study ignores local mismatch and all micro effects,

Figure16 shows the dominant importance of the application environment. All models agree, for instance, that a lifetime

at delta 10 C (cycling high to low), will be reduced 1/10 X, if the in-service delta is instead 50 C. Designers use these curves to validate and guide thermal-management and duty-cycle considerations. These curves also are central to projecting in-service life, based on known accelerated test data. For instance: 2000 cycles at delta 100C (a typical 0-100C test) will net you 500,000 cycles if field conditions are delta 10C.

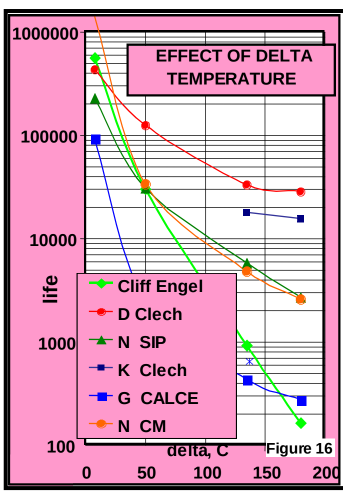

Figure 16

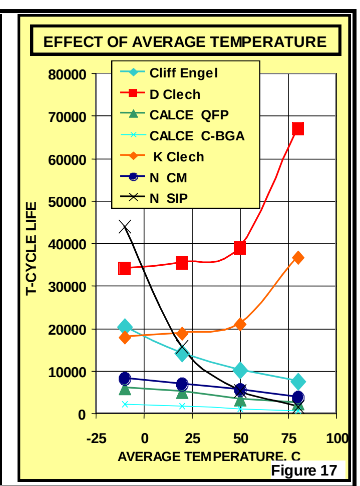

Figure 17

The effect of average temperature (Figure 17) is less clear, from this exercise at least. Three models show the expected reduction in life with increasing temperature. One model, used by two participants, shows an apparent reversal.... better life at higher temperatures. The reason (possibly errors of input or operation) is unknown and is being investigated.

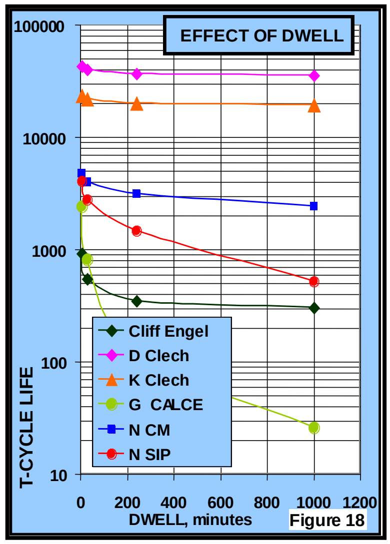


Figure 18 shows general agreement that increasing dwell time at the profile extremes will have a 2-3X effect in the 10- to 100-minute range, but progressively less deleterious effect farther out. These mission-condition responses can offer powerful justification and direction for thermal-management considerations.

**Conclusions from the Parametric-Response study**

1) Within narrow ranges, when explored close to known baseline facts, the use of this response-surface method should get you within a few percent of the correct prediction. Exploring the response-surface map residing in your model will reveal where slopes are steepest or where farther extrapolation makes no sense. Certainly the mid-range slopes can be used to identify which are the first-order effects in hardware-design or materials-selection considerations

2) The impact of the mission conditions can be much more critical than minor squabbles about the effects of pitch, or local CTE, or die-edge shadow, etc. For instance, if the mission delta in not correctly known or not managed, predictions and actual life-times will be two or more order-of-magnitude off. It is crucial that t-cycle conditions to be encountered in service are well known, in order to predict life correctly. It is similarly essential crucial that the requirements (conditions and life expectations) be known, before any design or analysis effort be made to determine if the hardware will be "good enough". Parametric analysis will help in all "what-if" studies in design and application

3) Every good model should be useful for most parametric-response tasks, within the limits of its coverage. The responses will include the effects of materials and geometry, as well as t-cycling conditions.

**Overall conclusions**

1) Prediction, and even the act of using prediction software, remains an art. No clear "winner" emerged in this study. All the models responded generally in sync, but GUI and specific capabilities varied. Any of these models, with proper experience, could predict to within perhaps an order of magnitude. Certain geometries are apparently outside some model's capabilities; but upgrades might be in development.

2) The best way to get close to an accurate absolute life prediction is, in the authors opinion, to start with a known fact (credible test results or a field experience), then to use parametric analyses, to interpolate or near-extrapolate to a desired condition.

3) It is hoped that broader upgrades and possibly new models might arise to handle grid-array packages, and warp effects, and underfill effects, and the troublesome combined t-cycle and vibe-shock effects, and especially all these tasks in lead-free systems.

4) Note that this exercise does not reflect, in any way, the potential value of proper use of any particular model or viewpoint or teaching, offered by the true experts in this field, some mentioned above. Properly wielded, backed up by experience and typically by empirically-based tailoring, any good model can come close enough for most purposes. The intent of this exercise was to offer a broad view and to hopefully nucleate informed discussion. This will become increasingly necessary as the lead-free alloy situation stabilizes, and as plating artifacts are massaged out, and workers need to know the fundamental thru-the-fillet shear-fatigue life capability of a specific solder joint and substrate combination. Hopefully, the appropriate physics will be created to accommodate these lead-free alloys, and models are created that will agree closely with actual test data.

Acknowledgements

The author thanks the participants, for their diligent pursuit and difficult struggles thru the author’s guidelines and inputs, as well as the advisory experts in industry and academia for their encouragement.

# PREDICTOR MODEL … ROUND ROBIN

TOM CLIFFORD, MARCH 2008,
APEX, LAS VEGAS

# CONTENT

1) WHAT IS A PREDICTOR MODEL?
2) WHY COMPARE PREDICTOR MODELS?
3) WHY USE A "ROUND ROBIN" ?
4) THIS STUDY: GROUND RULES
5) RESULTS , COMPARISONS , CONCLUSIONS
6) PARAMETRIC STUDY AND RESULTS
7) CONCLUSIONS, AND Q & A

# CONTENT

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# WHAT IS A PREDICTOR MODEL?

**PREDICTS THERMAL-CYCLE LIFE ( … CYCLES TO FAILURE…) FROM SCRATCH: INPUTS ARE HARDWARE DESCRIPTION AND CONDITIONS.**

**HANDLES CLASSIC CYCLIC-FATIGUE-FAILURE, THRU THE SOLDER-JOINT, DUE TO CTE-MISMATCH.**

**DOES NOT HANDLE PREMATURE FAILURES AT INTERFACES, LIKE BLACK-PAD OR VOIDS, etc ……. DOES NOT HANDLE OTHER FAILURE MODES SUCH AS IMPACT…. OR CONTRIBUTING FACTORS LIKE WARPING OF COMPONENT OR PWB.**

# CONTENT

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# WHY COMPARE  PREDICTOR MODELS

1) DESIGNERS NEED TO PREDICT LIFE, TO ASSURE RELIABLE PRODUCT APPLICATION.  THAT'S CRITICAL.    PREDICTION, FROM SCRATCH, IS VERY DIFFICULT.

2) MOST DESIGNERS ARE DISTRACTED, IMMERSED IN A MILLION OTHER DETAILS, AND ARE NOT EQUIPPED OR FUNDED TO DEVELOP EXPERTISE.

3) THEY NEED A DESK-TOP, INTUITIVE, USER-FRIENDLY RESOURCE TO TO ARRIVE AT A T-CYCLE LIFE PREDICTION.

4) SEVERAL MODELS AND RESOURCES ARE IN USE AND AVAILABLE, COMMERCIAL AND IN-HOUSE. MOST REQUIRE HIGH SKILL LEVEL.

5) MUST SELECT AND COMMIT TO ACQUISITION AND TRAINING.

6) COMPARISON OF AVAILABLE MODELS IS A GOOD START.

# CONTENT

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7) CONCLUSIONS,  AND Q & A

## WHY USE A “ROUND ROBIN” ?

A “ROUND ROBIN” IS THE CLASSIC METHOD TO COMPARE LABS, OR INSTRUMENTS, OR SKILLS.

ALL PARTICIPANTS ARE GIVEN THE SAME “UNKNOWN”. THEY ANALYZE THIS “UNKNOWN” INDEPENDENTLY.

(THE “ACTUAL” VALUE IS NOT PROVIDED TO THE PARTICIPANTS UP-FRONT)

RESULTS ARE THEN SHARED, COMPARED. …. AND DISCUSSED.

# CONTENT

1) WHAT IS A PREDICTOR MODEL?

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# THIS STUDY:  GROUND RULES

* TEN WELL-CHARACTERIZED COMPONENTS WERE CHOSEN, FOR WHICH THERE WAS CREDIBLE ACTUAL T-CYCLE LIFE.

* THESE COMPONENTS SPANNED A WIDE RANGE OF GEOMETRIES.

* ALL WERE MOUNTED ON MULTILAYER POLYIMIDE PWB.

* ALL INVOLVED Sn63 PLATINGS AND FINISHES.

* ALL WERE TESTED AT THE SAME TIME.

* PROPER STATISTICS, SAMPLE-SIZE, DATA-REDUCTION

* “FAILURE TIME” IS DEFINED AS NUMBER OF CYCLES AT THE POINT THAT CRACKS PROPAGATED THRU 100% OF THE FRACTURE-PLANE AREA.

# THIS STUDY: GROUND RULES (contd)

* PARTICIPANT VOLUNTEERS SPANNED SEVERAL MIL-AERO ORGANIZATIONS AND LABS.

* EACH PARTICIPANT WAS TO USE HIS OWN PREDICTOR MODEL. SEVERAL PREDICTOR MODELS WERE INCLUDED.

* THE STUDY MANAGER (ME), HAD NO INTEREST OR INPUT INTO THE TYPE, DETAILS, OR OPERATION OF THE PARTICIPANTS' MODELS.

* EACH PARTICIPANT WAS PROVIDED THE SAME SUITE OF AVAILABLE INFORMATION ON EACH COMPONENT.

* EACH PARTICIPANT WAS PROVIDED THE SAME SET OF CONDITIONS (TEMPERATURE EXTREMES AND RAMPS AND DWELLS): IDENTICAL TO THE T-CYCLE TEST CONDITIONS USED TO OBTAIN THE ACTUAL TEST DATA.

* STUDY WAS INITIATED … RESULTS OBTAINED … AND COMPARED

# GROUND RULES (contd)

**NOTE THE PREMISES:**

1) A PREDICTOR MODEL THAT CAN ACCURATELY PREDICT THE LIFE IN AN ACCELERATED T-CYCLE TEST (ie -10C to + 125C, 30 minute ramps and 30 minute dwells) SHOULD BE ABLE TO SIMILARLY PREDICT THE FIELD-SERVICE LIFE (example 10 C to 30 C, 120 minute ramps, 240 minute dwells).

2) IT'S VIRTUALLY IMPOSSIBLE TO DO A RATIONAL, STATISTICALLY-VALID, REAL-WORLD, T-CYCLE "TEST"… SPANNING MANY YEARS AND MANY TENS OF THOUSANDS OF CYCLES.

3) THEREFORE, WE COMPARE THE MODELS BASED ON THEIR ABILITY TO PREDICT ACTUAL KNOWN TEST T-CYCLE LIFE.

# Details of Components É. Predictor Model Round Robin Table 1

| # | description | dimensional details (dims in mils) | CTE (1) |
|---|---|---|---|
| -0- | circuit board | 135 thick 20-layer polyimide / glass | 17.5 |
| 1 | 0402 SMR | 19X39, 9caps, 29X35 lands, 28X35 foot, 24X30 fracture plane, fillet to cap, 1.2 mil sldr thick, 21 toe. | 6.4 |
| 2 | 2010 SMR | 99X196X 21, 20 caps, 65X121 lands, 51X110 foot, 40 X115 fracture plane, 1.1 mil solder film, 9 toe. | 6.4 |
| 3 | 52 I/O LCCC | 750X750 , 950 cas diag, 25 cas-land width, 34x96 lands, fillet3/4up .85 solder, 36 toe | 7.5 |
| 4 | little Plastic FP 28 I/O 50 pitch | 273X774X90, 490landtoe-toe, 655 body-attach diagonal, 715 foot-center diagonal, 10X16 leads, 35X121lands, 75 degree angle,15 radius, 28 straight lead-length, 11shoulder, 11X40 foot, 30X94 wetted foot, 28x55 fracture plane, toe fillet to top of lead, heel fillet 23 up heel, 23 heel fillet , 23 toe fillet, 0.9 mil sldr film thick | 14.0 |
| 5 | big Plastic QFP 144 I/O 25 pitch | 1089X1089X140 body, 1320X1320 land toe-toe, 1382 body-attach diag, 1490 foot diagonal, 6X11 leads, 18X120 lands, 80 angle, 20 radius, 60 straight H, 15 shoulder, 10X38 foot, 18X93 foot, 11x50 fracture plane, toe filletto top, heel fillet, 15 up heel, 20 heel fillet length, 38 toe fillet length, .8 mil sldr thick | 14.0 |
| 6 | little ceramic FP 28 I/O 50 pitch | 393X720X90 body, 696 landtoe-toe, 720 bodydiag, 875 foot diag, 5X17leads, 35X12lands, 70 angle, 21 radius, 30 straight lead-length, 23 shoulder, 17X44 foot, 35X90 wetted foot, 25x50 fracture plane, toe fillet to top, heel fillet18 up, 30 heellength, 35 toe length, .8 mil sldr thick | 7.5 |
| 7 | Big ceramic QFP 192 I/O 25 pitch | 950X950X94 body, 1495X1495 landtoe-toe, 1521 bodydiag, 1740 foot- diag, 4.5X6leads, 20X120 lands, 85angle, 20 radius, 80 straight lead-length, 40 shoulder, 6X45 foot, 15X80 wetted , 6.6x13 fracture plane, toe fillet to top, heel 15 up, 33 heel length, 36 toe length, .8 mil sldr thick | 7.5 |
| 8 | Big P-BGA, Amkor 1517, 1mm | 1572 sq body, 2068 ball diag, 16 collaps ht, 28 fattest, 25at fracture plane, 20.5 dia land NSMD on PWB, 22.5 land slite SMD on package, | 15.0 |
| 9 | Big C-BGA 625 full, 1.0mm | 1281 sq body, 1692 ball diag, 36 assembled ht, 35 dia fattest part, 29 dia at fracture plane, 37 dia land NSMD on PWB, 35 land on package, 1 mil thinnest film, fillet covers land and 8 mils up ball sides, 75% fails at bottom fillet. | 5.3 |
| 10 | Big Ceramic ColGA, 625, 1.27mm | 1281sq body, 1692 ball diag, Raychemcolumns, 88 ht, 21coldia, 29 dia at f plane, 37land NSMD on PWB, 35 land on package, 1 mil film base, fillet 10 up column sides, and down 5 mils from package, 75% fails at bottom fillet. | 5.3 |

(1) CTE (weighted average from -10 to + 125).

| ROUND ROBIN ÉÉÉÉ PREDICTOR MODEL TABLE 2 SUMMARY | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **COMPONENTS / DESCRIPTIONS** (see Details). **AND PREDICTED F50s** | | | | | | | | | |
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| **PREDICTOR MODELS** | **0402 SMR** | **2010 SMR** | **52 I/O LCCC** | **28 I/O P-FP** | **144 I/0 C-QFP** | **28 I/0 C-FP** | **192 I/O C-QFP** | **big P-BGA** | **big C-BGA** | **big CCol-GA** |
| **Cliff (Engel) 100%** | 1844 | 25 | 1 | 20 | 541 | 63 | 607 | 2819 | 0.2 | 6469 |
| **Cliff (Engel w 'correct' solder) 100%** | 15380 | 256 | 13 | 332 | 11540 | 1349 | 12960 | na | 26 | na |
| **D (Clech)** | 1728 | 2646 | 762 | 29320 | 40,140 | 38840 | 14400 | 963 | 244 | 6228 |
| **B (Engel)** | 31981 | 632 | 37 | 209 | 85814 | 5669 | 132560 | | | |
| **G (CALCE)** | 33025 | 811 | 431 | 29215 | 130000 | 4611 | 3019 | 1451 | 961 | 1294 |
| **K (Engel)** | 1844 | 25 | 1 | 869 | 60621 | 1086 | 166 | 7066 | 175 | 1482 |
| **K (Clech)** | 4325 | 9078 | | 79110 | 21790 | 49030 | 3164 | | | |
| **N (SIP)** | 2237 | 502 | 119 | 1361 | 2258 | 944 | 792 | 2059 | 1089 | 1328 |
| **N (CM)** | 1667 | 82 | 310 | 561 | 2631 | 330 | 1844 | 1365 | 271 | 441 |
| **ACTUAL TEST RESULTS** | | | | | | | | | | |
| Cracks begin, (est) | 2500 | 300 | 75 | 1500 | 1400 | 1000 | 1200 | 250 | 50 | 500 |
| Cracks at 50% thru fracture plane area (est) | 8000 | 900 | 360 | 4800 | 3800 | 3600 | 3700 | 400 | 60 | 2500 |
| Cracks at 100% thru fracture plane area (est) | 10000 | 2800 | 500 | 5600 | 5000 | 4000 | 4600 | 550 | 75 | 3225 |

# CONTENT

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# RESULTS , COMPARISONS

THE FOLLOWING GRAPHICS SHOW THE COMPARATIVE NUMERICAL RESULTS OF ALL PARTICIPANTS' PREDICTIONS, FOR EACH COMPONENT.

NOTE THAT EASE-OF-USE DIFFERED SIGNIFICANTLY:

1) THE ENGELMAIER-BASED MODEL IS AN EXCEL SPREAD-SHEET THAT IS KEY-STROKE-SIMPLE, WITH ONLY 20-30 INPUTS.

2) THE "N-CM" IS MAIN-FRAME, ARCANE, COMPLEX AND VERY SLOW.

3) THE "N-SIP" IS DESK-TOP, BUT RELATIVELY SLOW.

4) THE CALCE AND CLECH/SRS MODELS ARE MID-RANGE, DEPEND ON SKILLS, AND ARE VERY CAPABLE.

# RESULTS

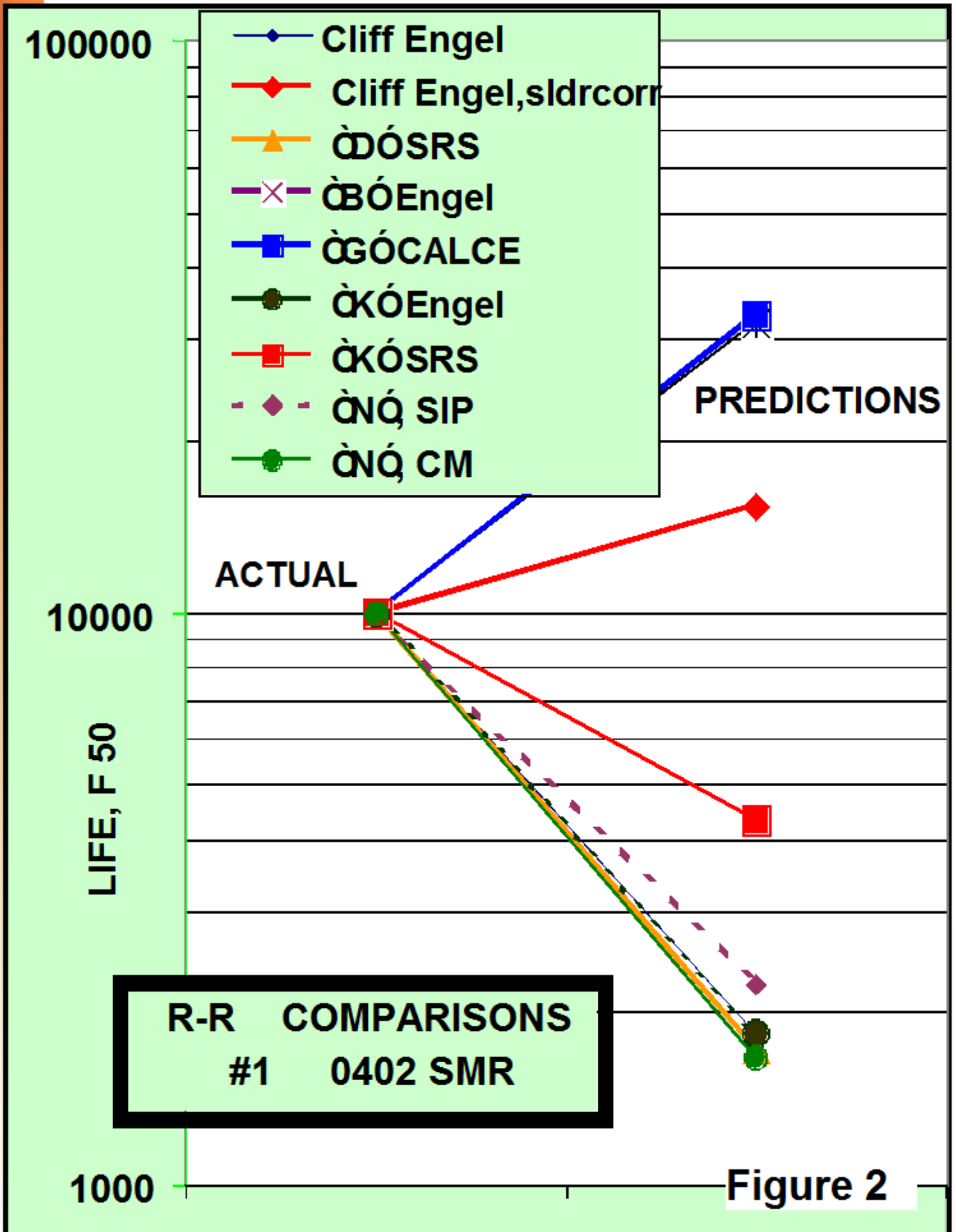



Figure 2

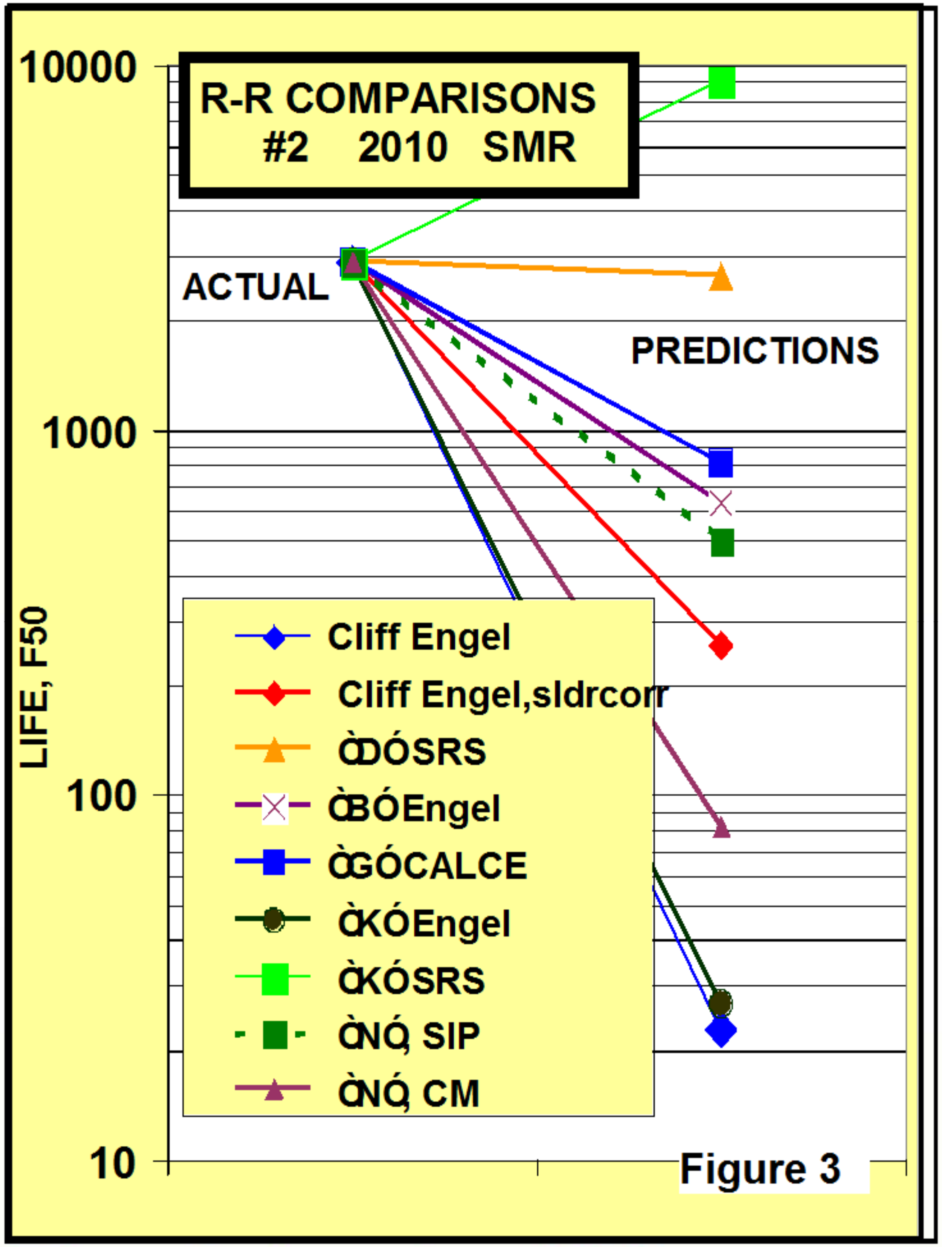



Figure 3

# RESULTS

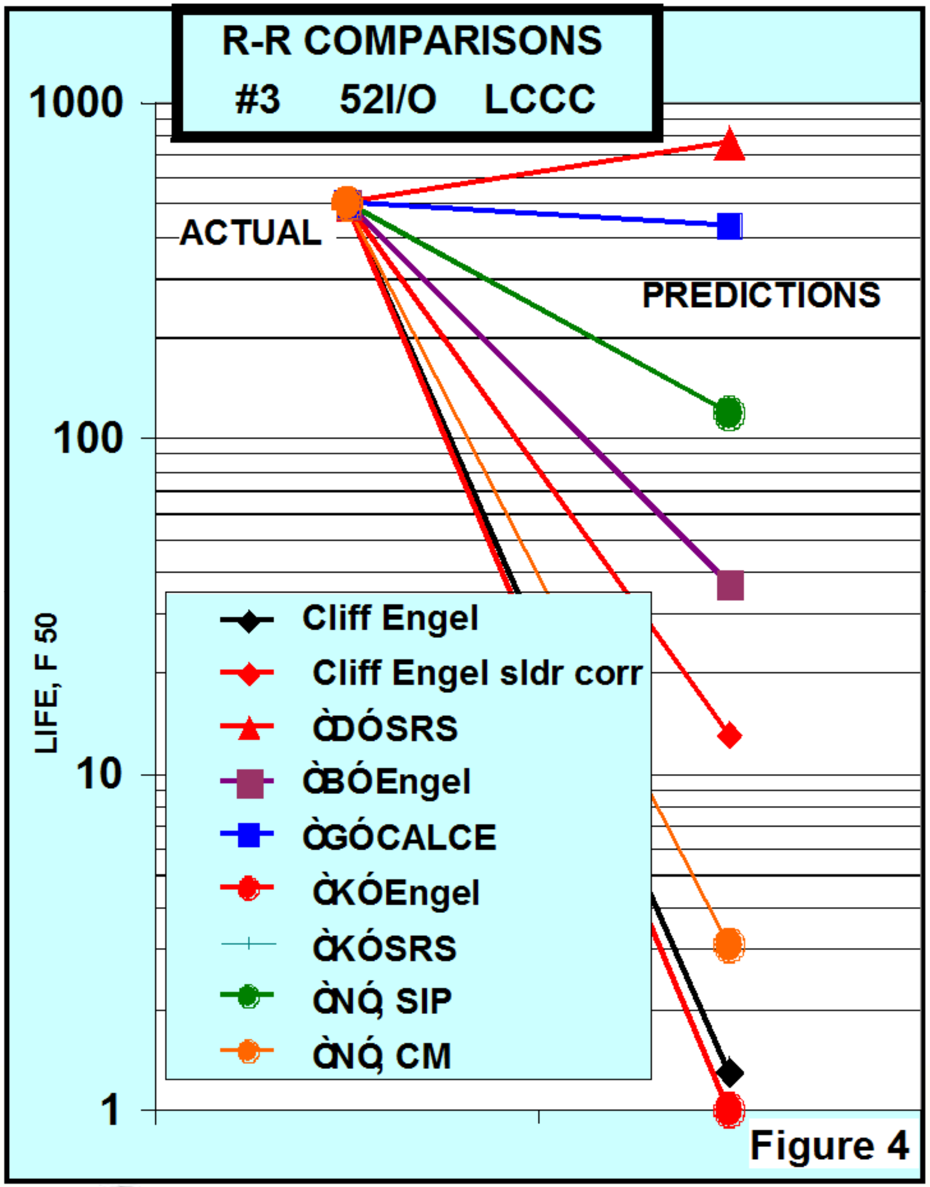


Figure 4

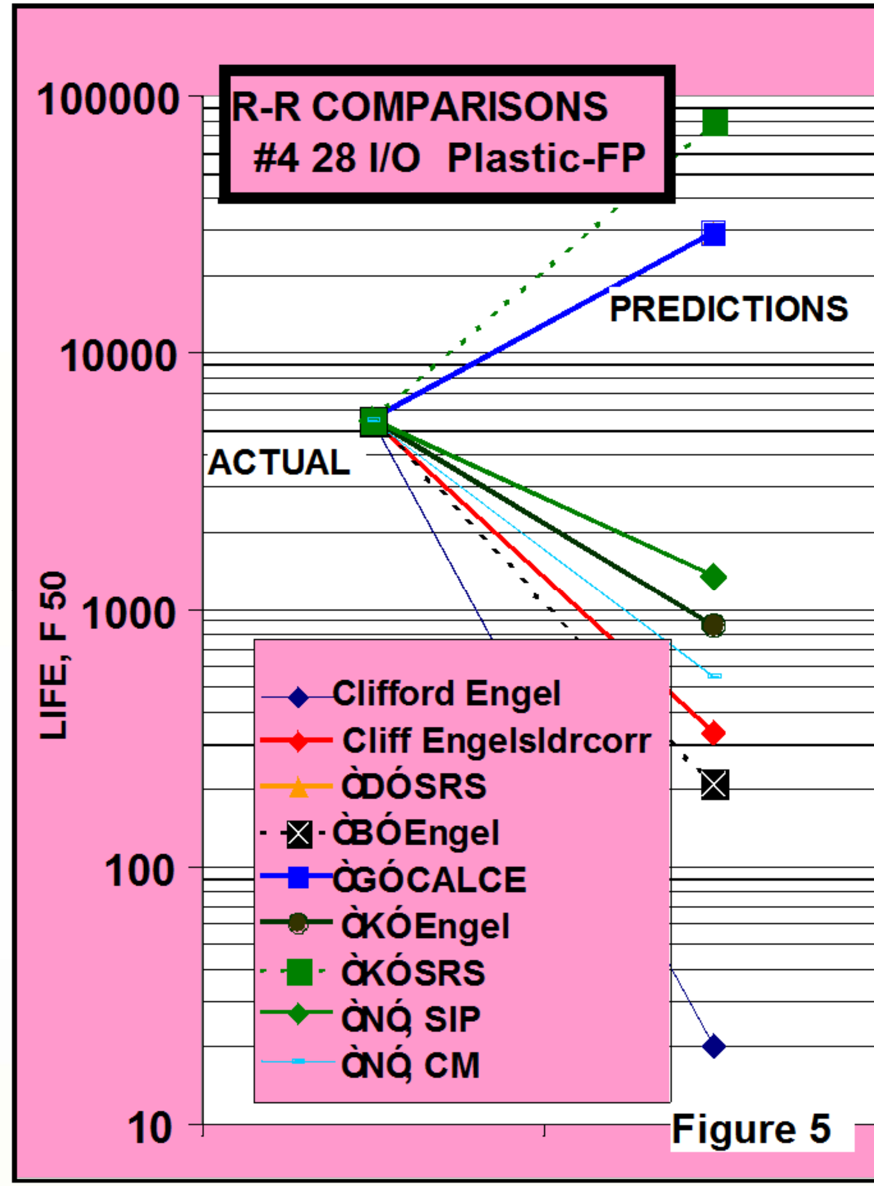


Figure 5

# RESULTS

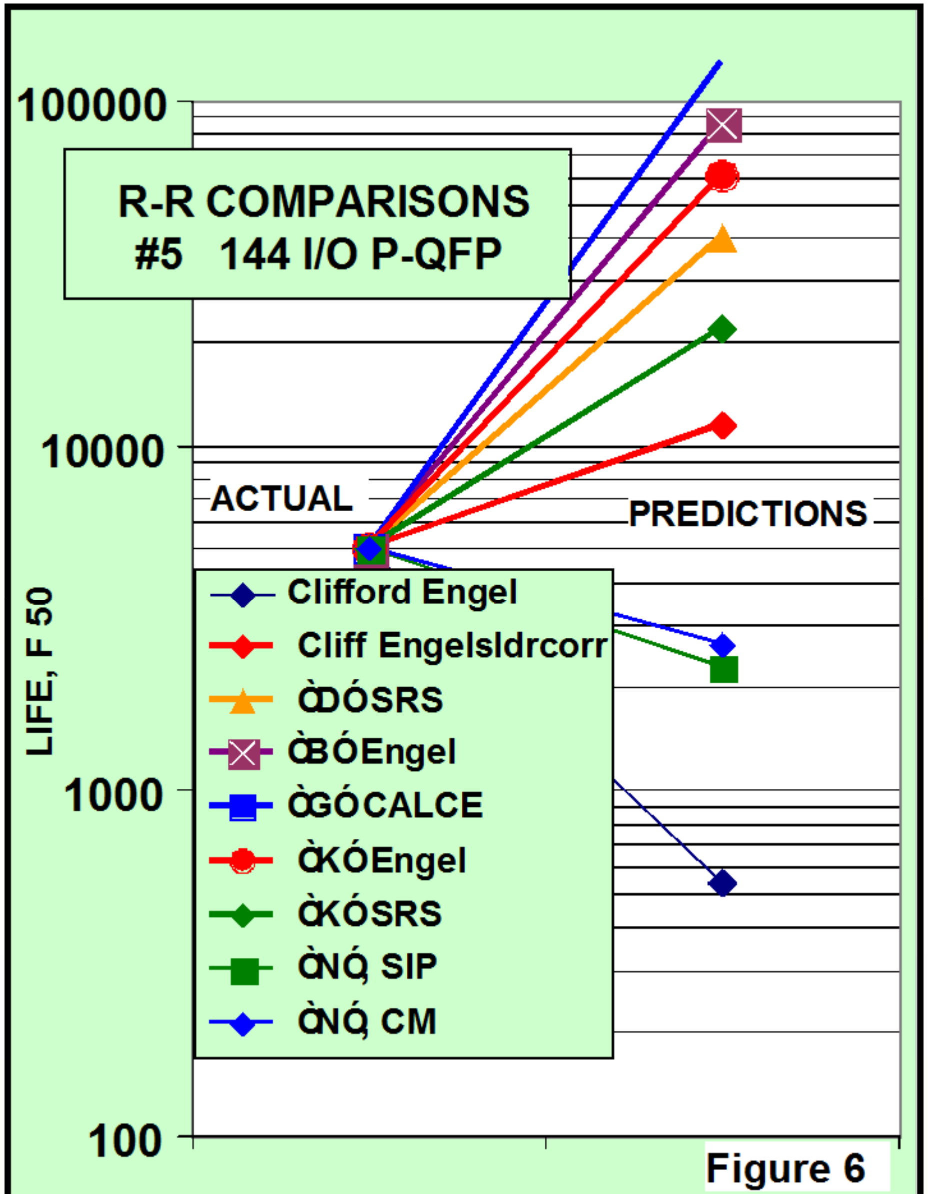



Figure 6

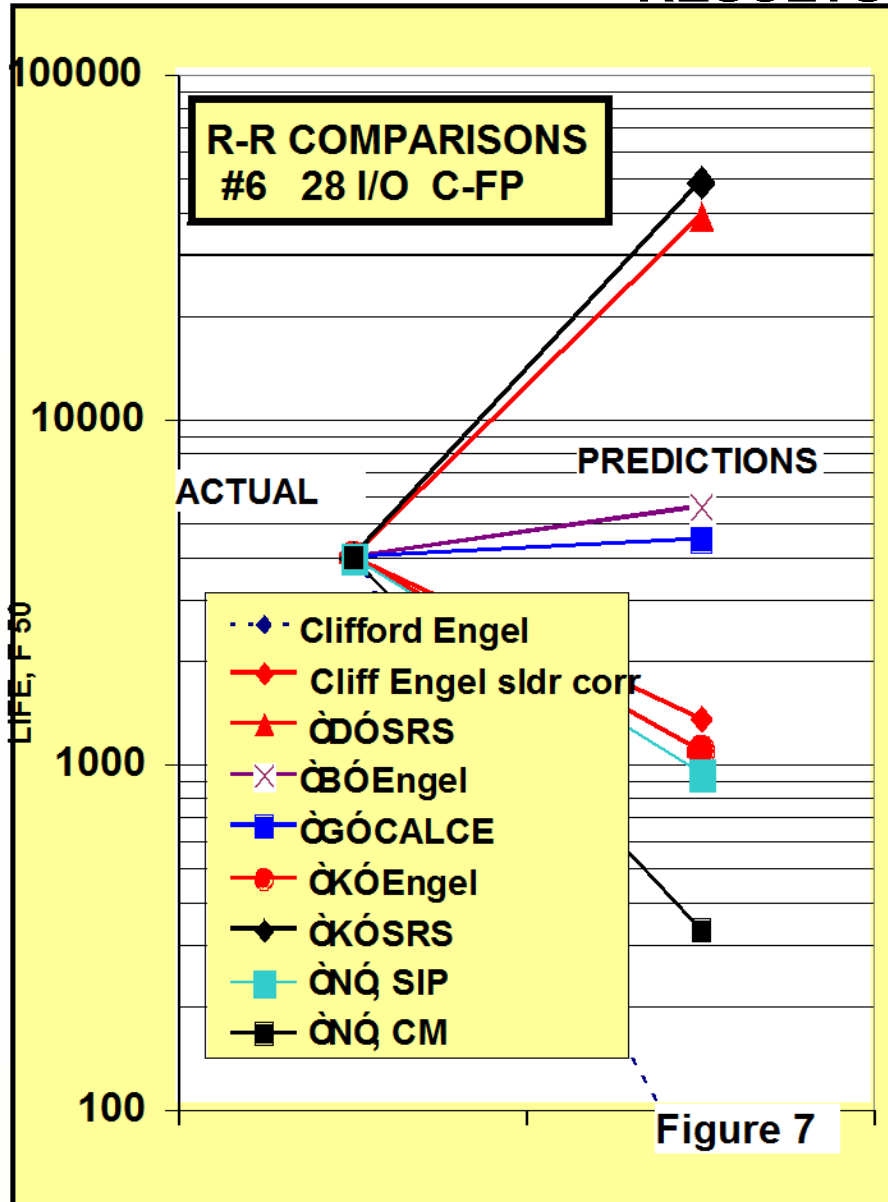



Figure 7

# RESULTS

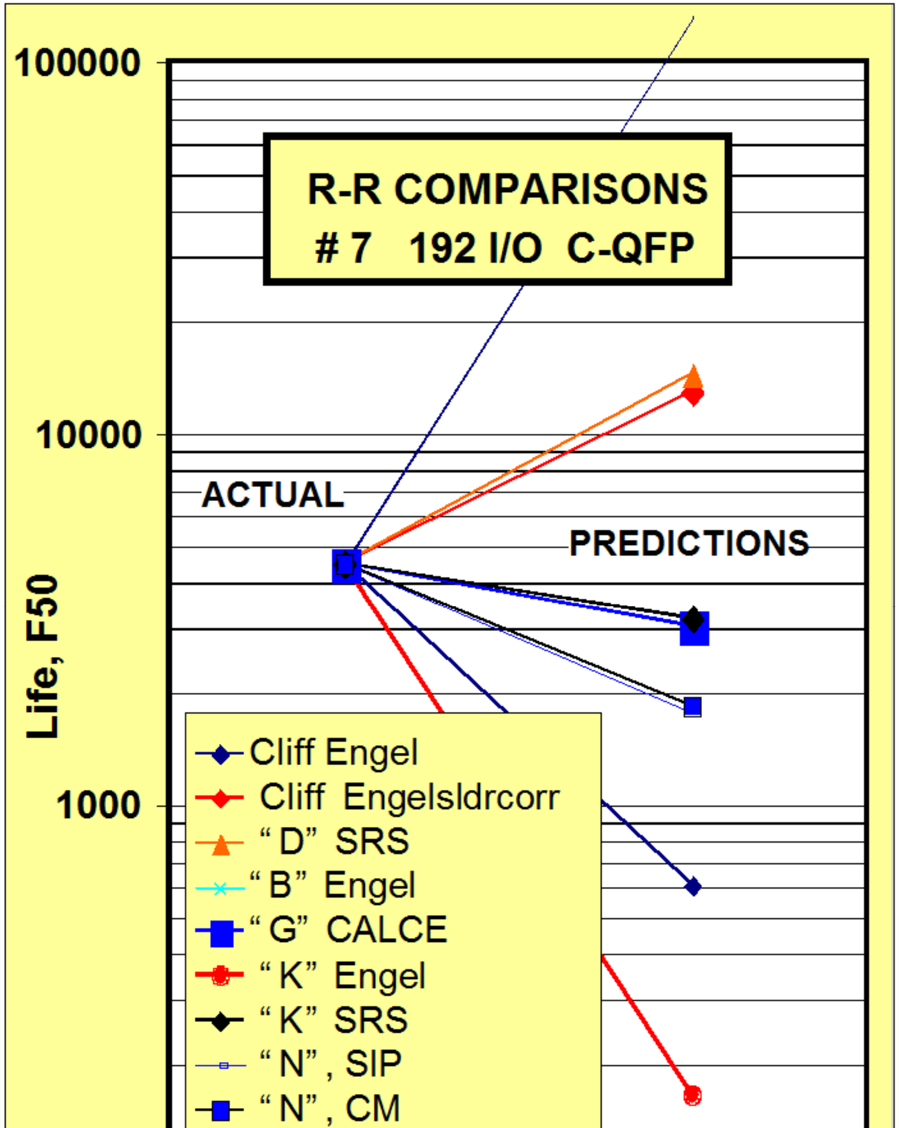


Figure 8

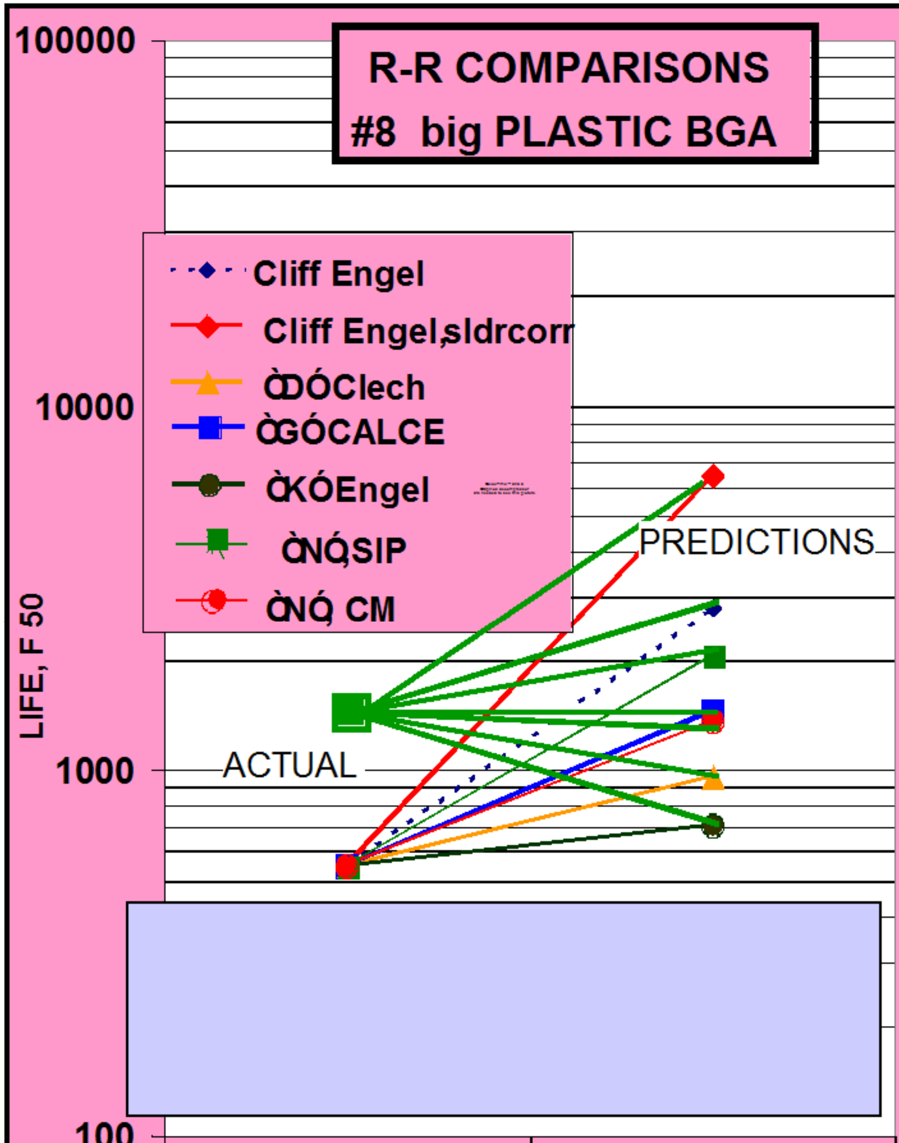


Figure 9

# RESULTS

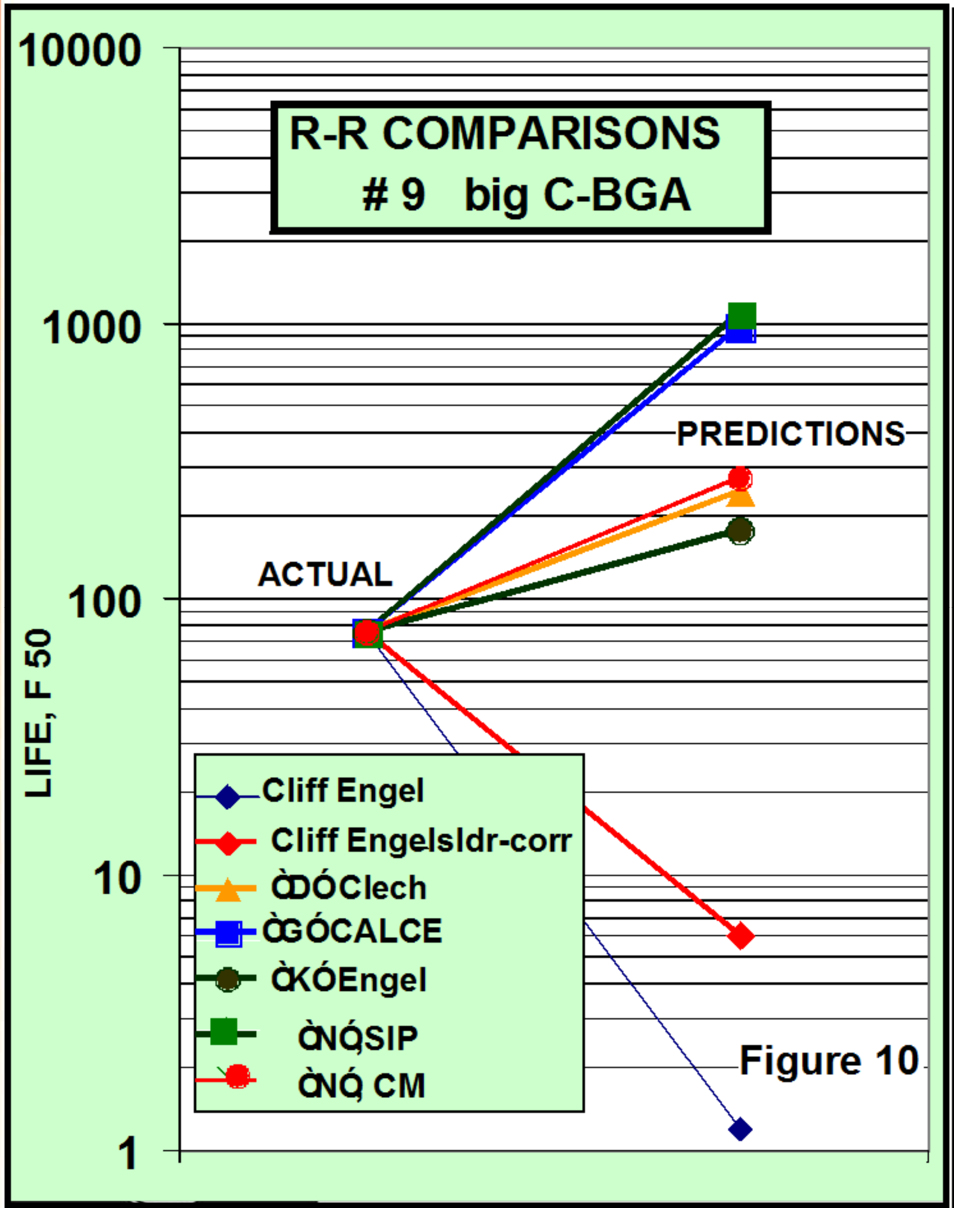



Figure 10

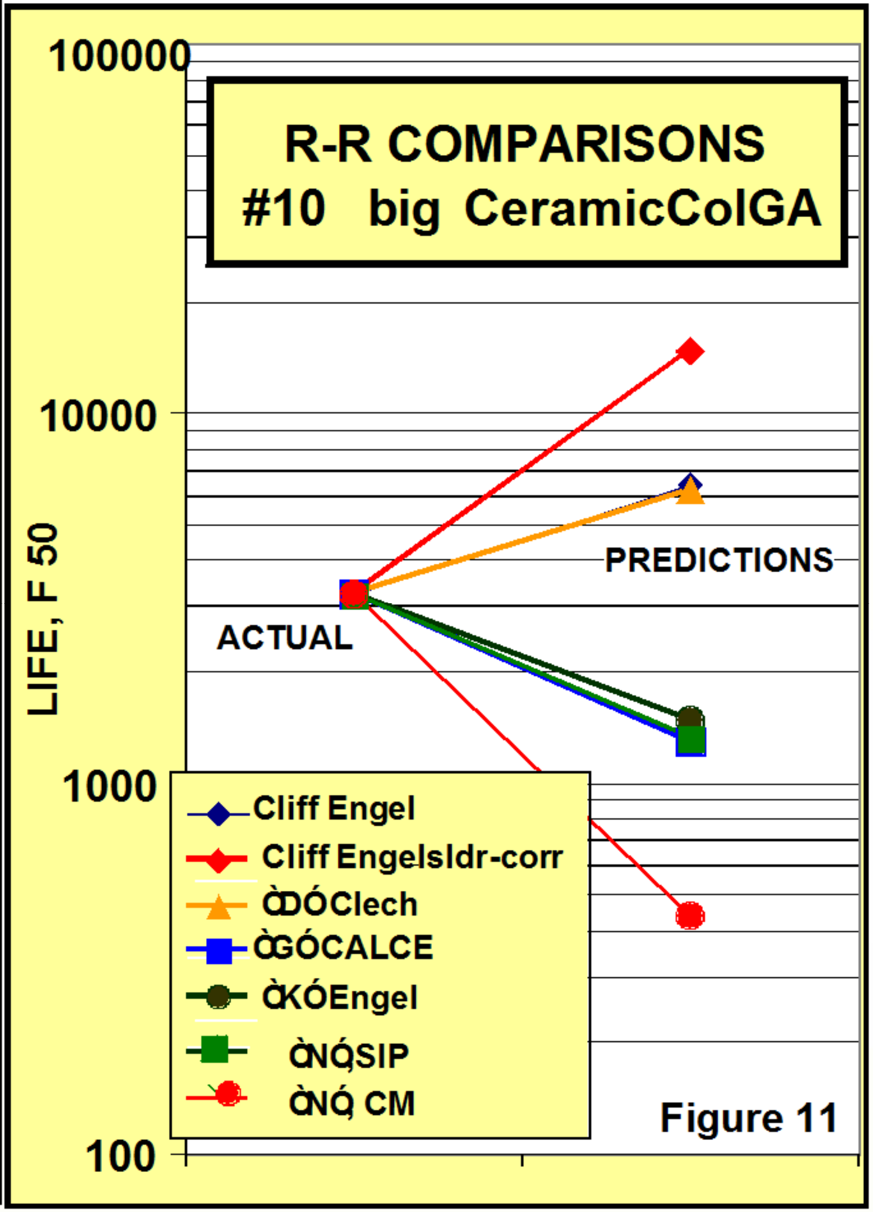



Figure 11

## CONCLUSIONS

THE <u>ACTUALS</u> FALL IN THE MIDDLE OF ALL THE PREDICTIONS. THAT'S REASSURING, FOR TESTING CREDIBILITY.

SOME MODELS PREDICT "HIGH" FOR SOME COMPONENTS, AND VICE VERSA. NO CONSISTENT PATTERN, BY MODEL OR BY COMPONENT.

YOU CAN COUNT ON PREDICTING <u>WRONG</u> BY A FACTOR OF 2-5X EITHER SIDE. FOR ANY COMPONENT, USING ANY MODEL. THAT'S NOT GOOD …..… BUT NOT UNEXPECTED.

SOME MODELS ARE MORE COMPLEX AND ALL-INCLUSIVE, PLUS PERHAPS MORE AMENABLE TO "TWEAKING" AND "FUDGE".
>>>> THAT IS LEGIT, IF IT'S BASED ON PROPER SCIENCE <<<<<

# CONTENT

# PARAMETRIC VARIANCE, OR TRANSFORM ……

# THE OTHER WAY TO "PREDICT" T-CYCLE LIFE

…. NOT TO PREDICT LIFE FROM SCRATCH (THE PREDICTOR MODEL) … BUT TO "TRANSFORM" FROM A KNOWN SITUATION TO A NEW SET OF CONDITIONS. FOR INSTANCE:

IF A CERTAIN COMPONENT IF FELT TO BE "OK" IN A GIVEN APPLICATION, HOW MUCH WORSE WILL BE A COMPONENT THAT IS 0.5" BIGGER, ALL ELSE EQUAL?

IF A COMPONENT WITH A PACKAGE CTE OF 16.5 HAS AN F50 OF 2250 CYCLES IN A GIVEN TEST, WHAT WOULD THE F50 BE IF THE CTE IS 6.8, INSTEAD?

IF A GIVEN COMPONENT/PWB IS KNOWN TO BE BARELY OK IN AN APPLICATION WITH A DELTA T OF 15 DEGREES, HOW MUCH WORSE WILL IT BE IF THE DELTA T IS 22 DEGREES?

**THIS PARAMETRIC STUDY WAS AN ADD-ON BONUS.**

**…… ONCE THE PARTICIPANTS GOT THEIR MODELS SET UP , THEY WERE ALL ASKED TO RUN SOME STANDARD CASES: VARY ONE FACTOR AT A TIME; SEE WHAT EFFECT THAT HAS ON T-CYCLE LIFE.**

**FACTORS INCLUDED HARDWARE PARAMETERS, AS WELL AS EXPOSURE CONDITIONS.**

**THIS EXERCISE WAS TO COMPARE “TRANSFORM” CAPABILITIES, AMONGST THE VARIOUS MODELS.**

## TABLE 3 ROUND-ROBIN, PARAMETRIC ANALYSIS AOVs, response surfaces

| AOVs É . hardware | 1) Use component 2, vary the solder thickness, mils | | | | 2) Use component 8, vary the diagonal dim, | | | | 3) Use component 7, vary the lead thickness @ constant width = .01 | | | | 4) use component 9, vary the component CTE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| parameter value | 0.5 | 2.0 | 5.0 | 20.0 | 0.5 | 1.0 | 2.0 | 3.0 | 3.0 | 5.0 | 8.0 | 10.0 | 3.0 | 6.0 | 9.0 | 12.0 |
| C Engel, | 4 | 100 | 834 | 20680 | 89240 | 16710 | 3238 | 1253 | 2870 | 133 | 13 | 5 | 4336 | 7417 | 14940 | 40920 |
| K Clech | 7691 | 11260 | 16990 | 47070 | 102 | 21 | 8 | 3 | 3612 | 3048 | 2556 | 2345 | | | | |
| B Engel | 107 | 510 | 19350 | 443474 | 102 | 21 | 8 | 3 | 288725 | 132596 | 20036 | 736 | | | | |
| D Clech | 2461 | 2962 | 4326 | 13509 | 5754 | 3168 | 1856 | 716 | 16140 | 13920 | 11770 | 11078 | 186 | 267 | 429 | 853 |
| G CALCE | 164 | 400.0 | 1700.0 | 7534.0 | | | | | 3745.0 | 3019.0 | 1558.0 | 118.0 | 311.0 | 600.0 | 1500.0 | 8000.0 |
| N-CM | 44 | 530 | 2095 | 14282 | 15059 | 8525 | 4029 | 2248 | 1763 | 1264 | 674 | 381 | 216 | 373 | 795 | 2905 |
| N-SIP- | 361 | 1231 | 2469 | 5466 | 5644 | 4614 | 3413 | 2592 | 1787 | 1667 | 1373 | 1101 | 1053 | 1315 | 1805 | 3035 |

| AOVs É . conditions | 5) use component 5 ...vary the delta @ Tave=40 | | | | 6) 5, vary the average temp, @delta=120 | | | | 7) 5, vary dwells, minutes | | | | 8) 10, vary F.xxx, @ beta 7 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| parameter value | 180 | 135 | 50 | 8 | -10 | 20 | 50 | 80 | 5 | 30 | 240 | 1000 | 63.0 | 0.1 | 0.010 | 0.001 |
| C Engel, | 164 | 1126 | 30220 | 558000 | 2035 | 1412 | 1010 | 743 | 912 | 541 | 350 | 302 | 2968 | 1107 | 797 | 543 |
| D Clech | 28480 | 33020 | 123700 | 433000 | 33960 | 35250 | 38860 | 66900 | 42780 | 40140 | 36680 | 35590 | 6228 | 1970 | 1342 | 914 |
| B Engel | | | | | | | | | | | | | | | | |
| K Clech | 15580 | 17760 | Crash | Crash | 17840 | 18690 | 20920 | 36650 | 23220 | 21790 | 20040 | 19450 | | | | |
| G CALCE | 274 | 431.0 | 2488.0 | 92000.0 | | | | | 2408.0 | 811.0 | 114.0 | 26.0 | | | | |
| N- CM | 2593 | 4819 | 33403 | 1E+06 | 8068 | 6860 | 5566 | 3857 | 4753 | 4003 | 3160 | 2438 | | | | |
| N-SIP | 2726 | 5772 | 30579 | 229800 | 43924 | 15701 | 5334 | 1623 | 4063 | 2794 | 1464 | 522 | | | | |

# RESULTS

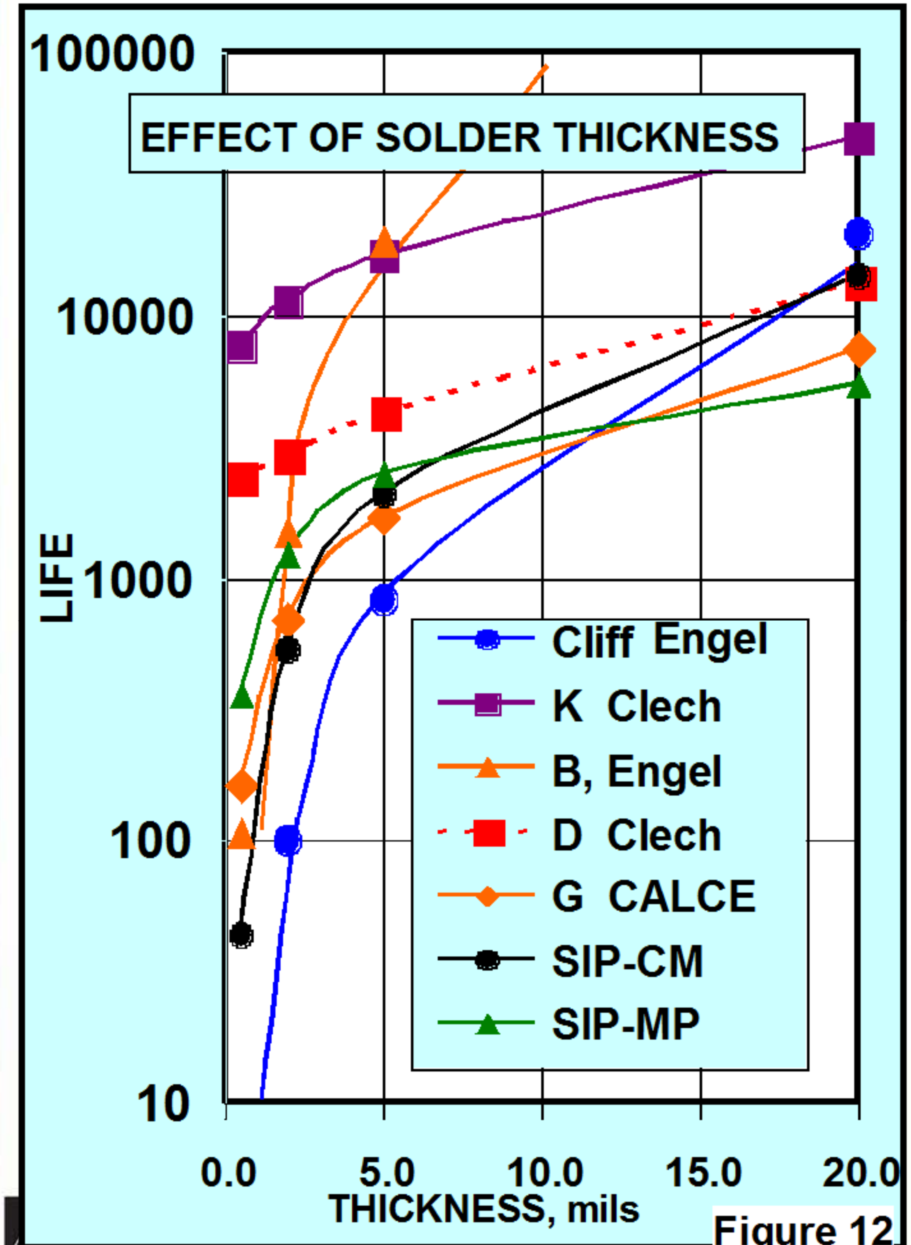



Figure 12

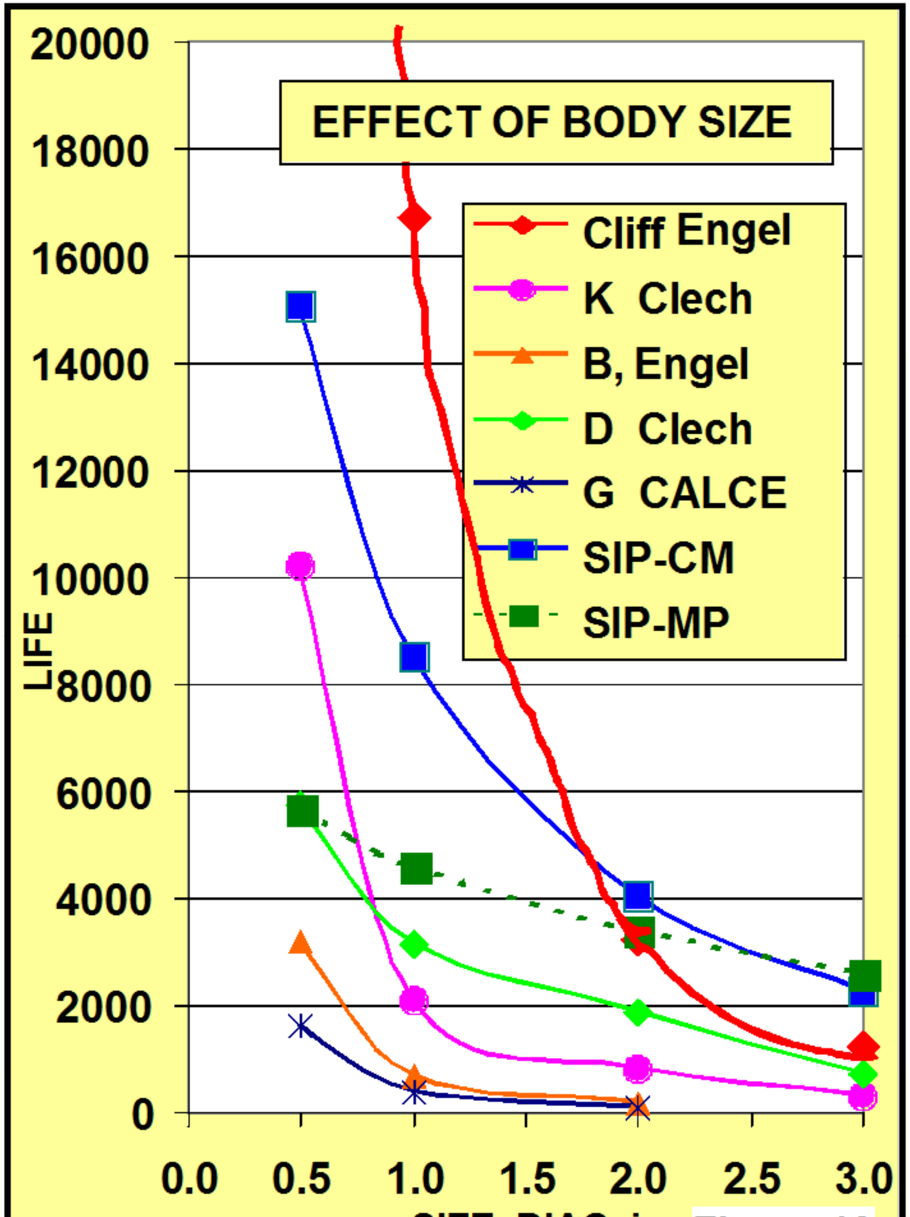



Figure 13

# RESULTS

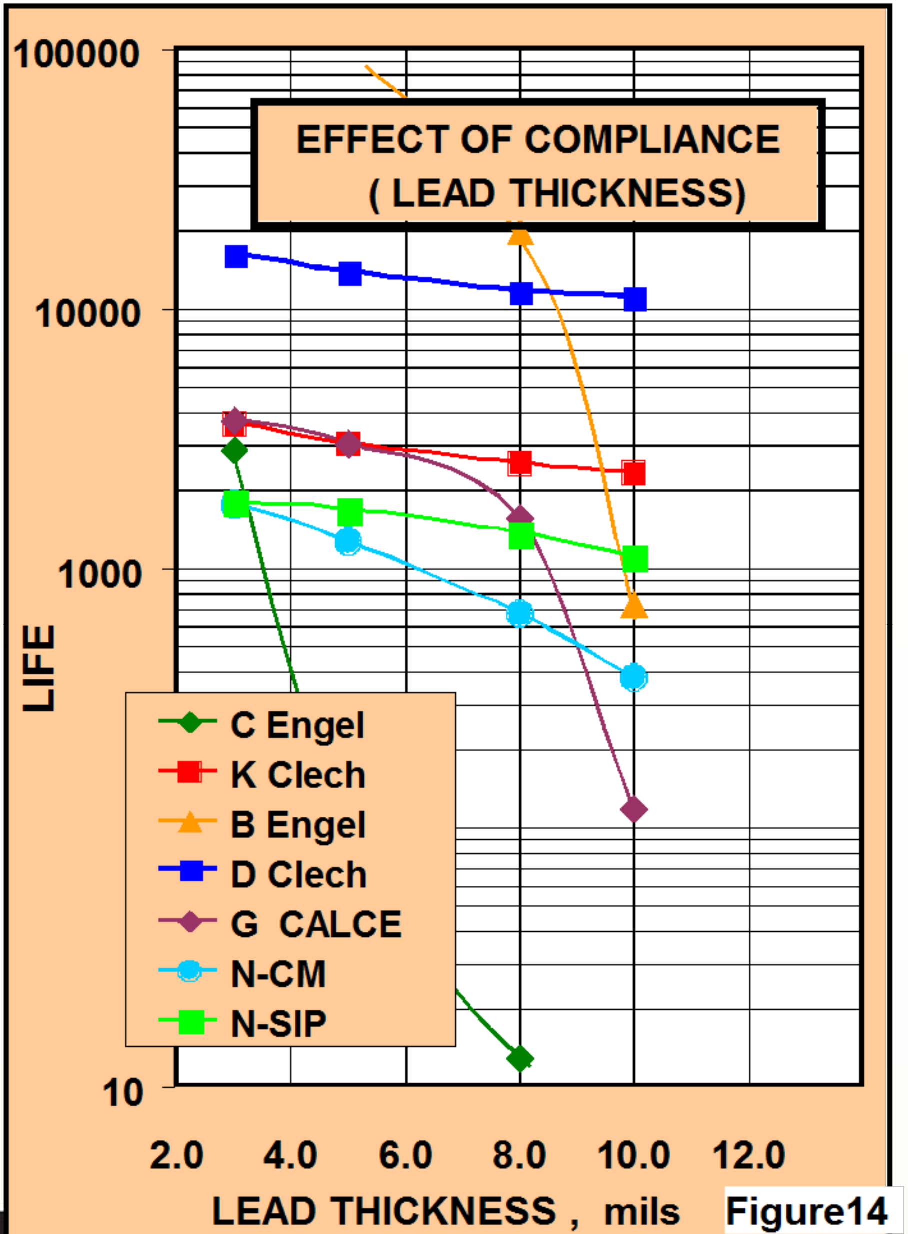



Figure14

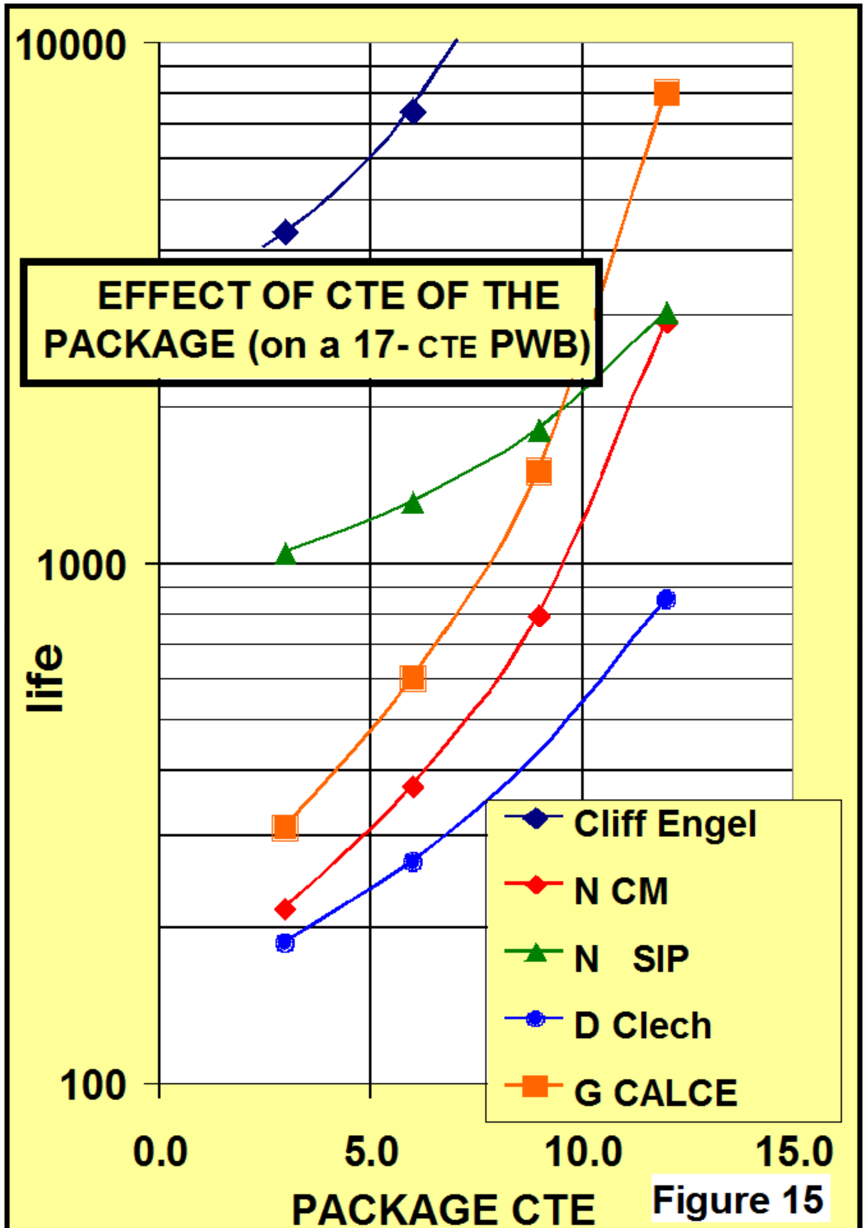



Figure 15

# RESULTS

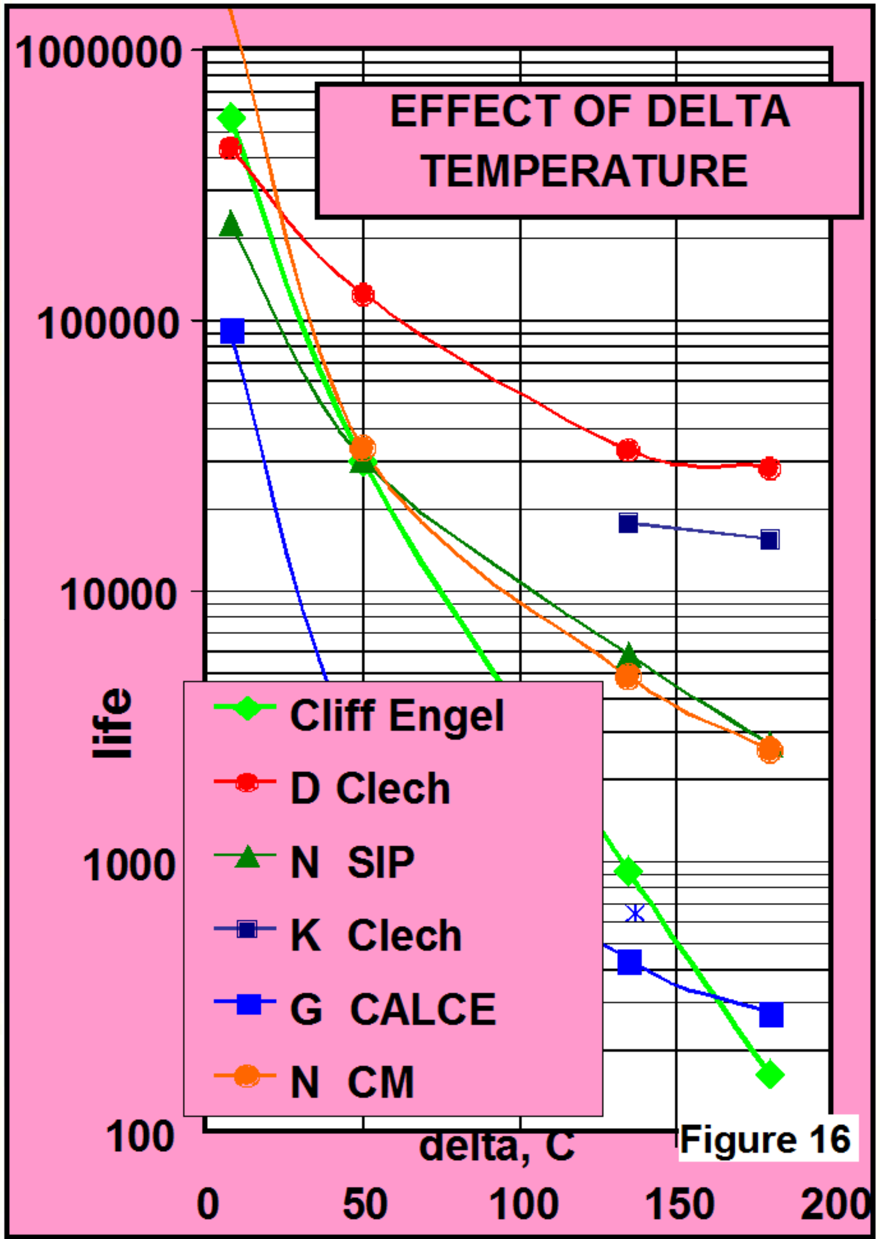



Figure 16

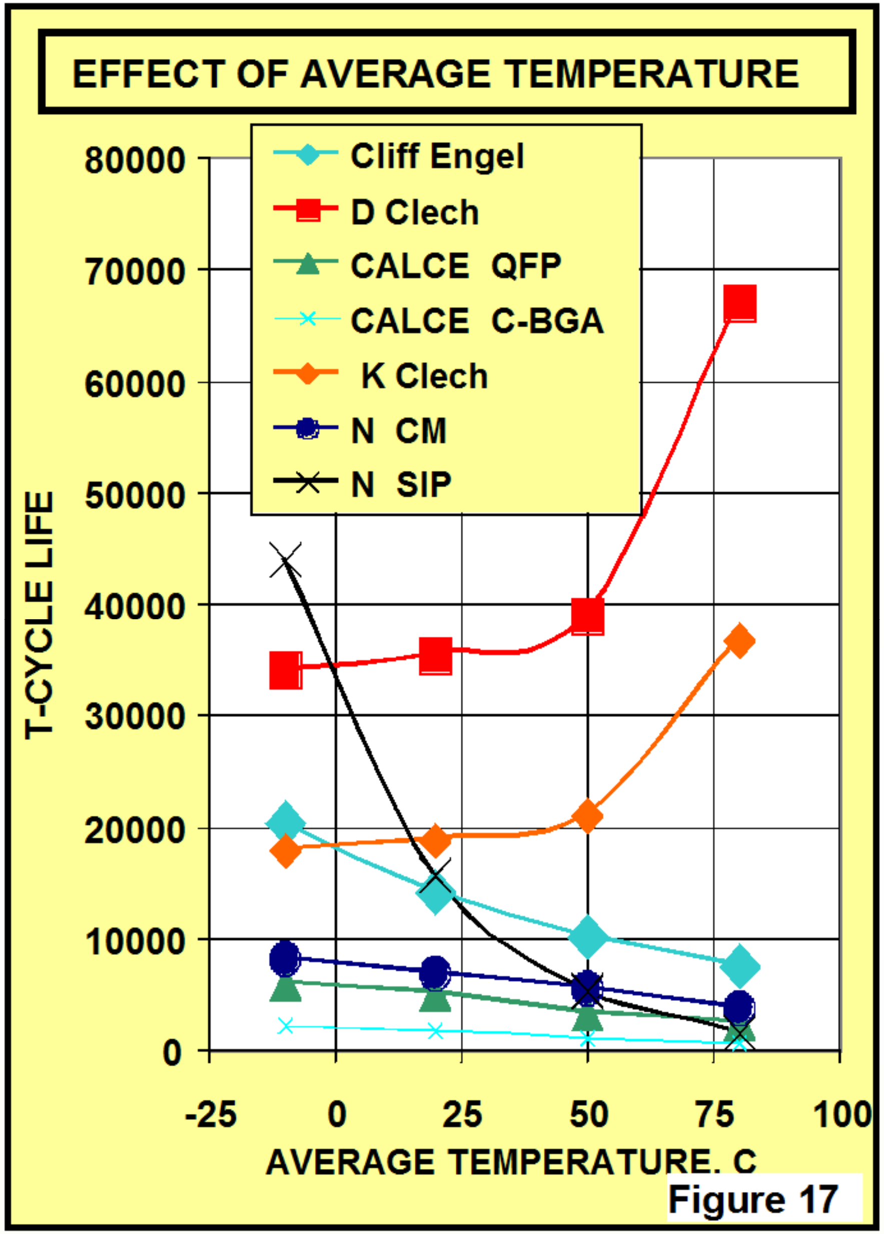



Figure 17

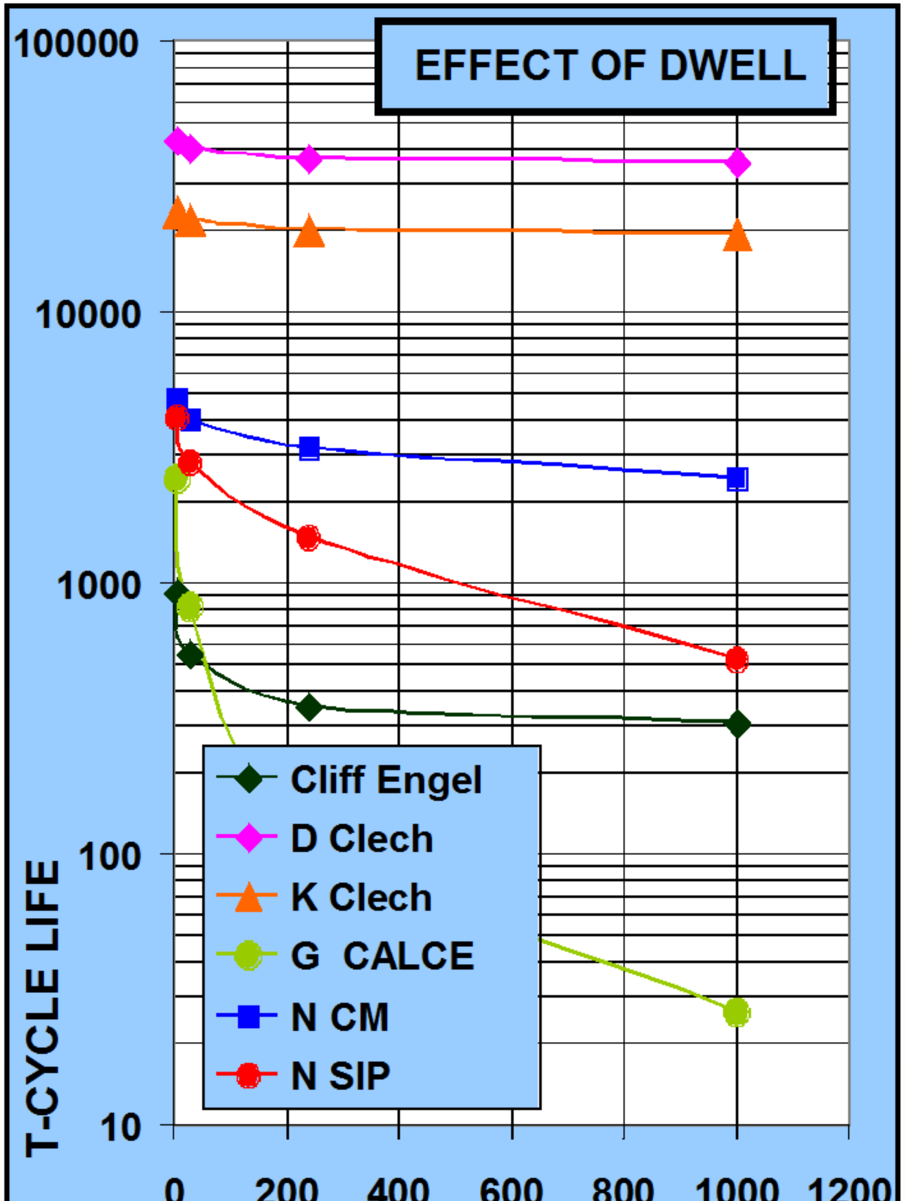



Figure 18

ALL THE MODELS AGREE …. ON ALL THE HARDWARE PARAMETERS. EVEN THOUGH THE ABSOLUTE VALUES DIFFER, THE SLOPE OF THE CURVE IS ESSENTIALLY THE SAME.

THAT MEANS IF ANY MODEL IS ASKED WHAT IS THE IMPACT OF A SMALL CHANGE IN ONE PARAMETER, THE CALCULATED IMPACT WILL BE APPROXIMATELY THE SAME.

THE ODD RESPONSE TO AVERAGE TEMPERATURE VARIANCE (FIGURE 17) IS UNEXPLAINED, AT THIS POINT

# CONTENT

1) WHAT IS A PREDICTOR MODEL?

2) WHY COMPARE PREDICTOR MODELS?

3) WHY USE A “ROUND ROBIN” ?

4) THIS STUDY: GROUND RULES

5) RESULTS , COMPARISONS , CONCLUSIONS

6) PARAMETRIC STUDY AND RESULTS

**7) CONCLUSIONS, AND Q & A**

# CONCLUSIONS

1) PREDICTIONS OF ABSOLUTE T-CYCLE LIFE REMAINS PROBLEMATIC.

2) SOURCES OF DIFFERENCES MIGHT INCLUDE THE MODELS' DEFINITION OF FAILURE, THE INCLUSION OF DIFFERENT FACTORS, AS WELL AS DIFFERENT INTERNAL MATH AND PHYSICS.

3) TRANSFORMS …. STARTING WITH SOME KNOWN SITUATION, THEN VARYING THE PARAMETERS …. LOOKS LIKE THE BEST BET, AT LEAST AS A FIRST CUT.

4) MUCH MORE WORK … DIFFERENT MODELS, MORE HARDWARE CASES, INCLUSION OF LEAD-FREE ALLOYS, etc, WOULD BE USEFUL.

5) FEEL FREE TO TRY YOUR FAVORITE MODEL USING THE TEN ACTUAL CASES DESCRIBED. NO FAIR PEEKING AT THE RESULTS, FIRST, THOUGH.

# AKNOWLEDGEMENTS

THE AUTHOR THANKS ALL THE PARTICIPANTS, CERTAINLY.

THE AUTHOR IS EQUALLY GRATEFUL FOR THE ENCOURAGEMENT BY INDUSTRY EXPERTS, TO DO THE STUDY AND TO DRAMATIZE THE IMPORTANCE OF HARDWARE FACTORS AND EXPOSURE CONDITIONS ON <u>SOLDER-JOINT RELIABILITY.</u>

THE WORKERS AT LOCKHEED MARTIN, WHO HELPED RUN THE T-CYCLE TESTS AND CHARACTERIZE THE SPECIMENS, WERE THE STRENGTH OF THIS ENDEAVOR. ANY ERRORS ARE ALL MINE.

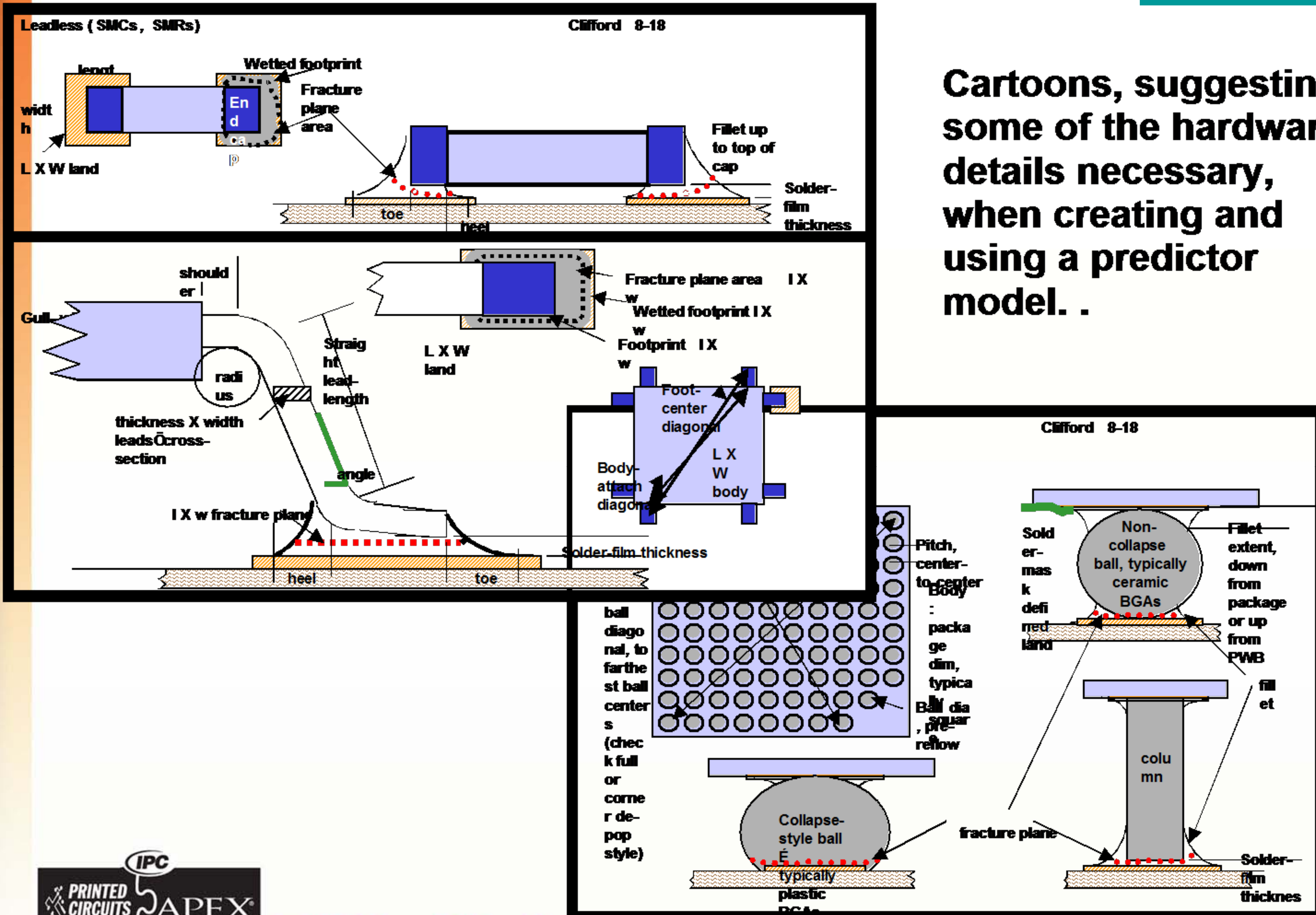
# Application guide -cycle life summary

## Typical SMT components, on conventional poly/glass PWBs

clifford 5-25-06

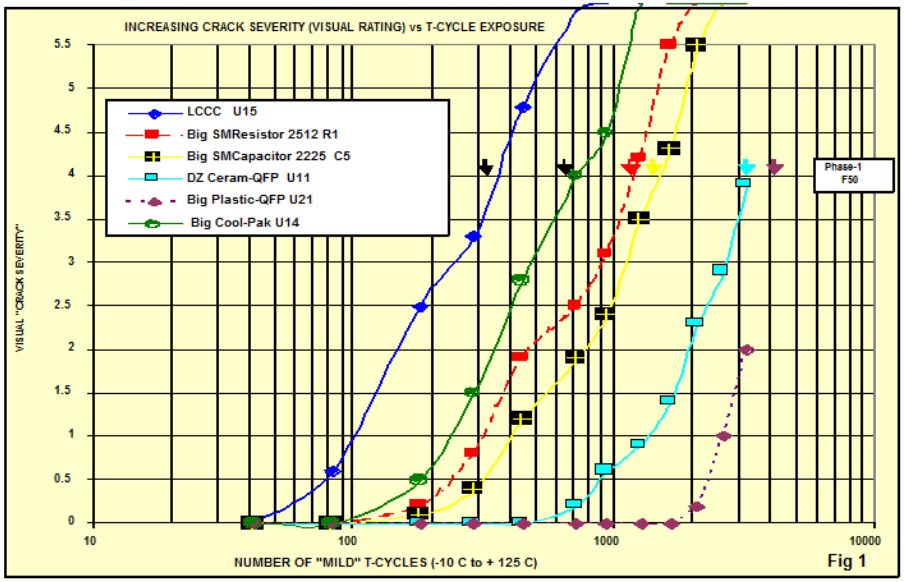
| typical parts' t-cycle life, in our standard test | | | | Extrapolated to likely LEO mission conditions | | |
|---|---|---|---|---|---|---|
| Examples of SMT parts' t-cycle life, on Poly/Glass PWBs, based on Phase 1 data, @ delta 135, ave 57 C. | F 50 at delta 135, from Phase 1, corrected to est all at 75% fracture plane | test data @ F .001 (from Phase 1) | F.001 test data, converted to 35 C | mild: **50,000 cycles** @ F.001, 20 min. dwell, 35 C average, **delta 11 C** | medium: **75,000 cycles** @ F.001, 20 min. dwell, 35 C average, **delta 13C** | severe: **100,000 cycles** @ F.001, 20 min. dwell, 35 C average, **delta 15 C** |
| big C-BGA 1.9" diag | 65 | 13 | 17 | 5349 | 3642 | 2621 |
| small C-BGA .8" diag | 130 | 27 | 33 | 10698 | 7285 | 5242 |
| big LCCC 68 I/O * | 195 | 40 | 50 | 16046 | 10927 | 7863 |
| medium LCCC 52 I/O | 320 | 66 | 82 | 26332 | 17932 | 12903 |
| small (20 I/O) LCCC | 750 | 155 | 193 | 61717 | 42028 | 30241 |
| big MELF | 900 | 185 | 232 | 74060 | 50433 | 36289 |
| big plastic BGA, 1.9" diag | 950 | 196 | 245 | 78175 | 53235 | 38305 |
| big chip cap or res, typ 2512 | 1250 | 258 | 322 | 102861 | 70046 | 50402 |
| big ceramic QFP 25 mil pitch | 1350 | 278 | 348 | 111090 | 75650 | 54434 |
| CColGA 1.6", IBM cols | 1500 | 309 | 386 | 123433 | 84056 | 60482 |
| CColGA 1.6", NTK cols | 1600 | 330 | 412 | 131662 | 89659 | 64514 |
| little chip cap or res (typ 1206) | 2300 | 474 | 592 | 189265 | 128885 | 92739 |
| CColGA 1.6", Ray cols | 2700 | 556 | 695 | 222180 | 151300 | 108868 |
| small ceramic FP 28 I/O | 3400 | 700 | 876 | 279783 | 190526 | 137093 |
| big Plastic QFP | 4800 | 989 | 1236 | 394987 | 268978 | 193542 |
| mBGA 3/4" diag* | 5000 | 1030 | 1288 | 411445 | 280185 | 201607 |
| tiny chip res (typ 0201) | 6000 | 1236 | 1545 | 493734 | 336222 | 241928 |

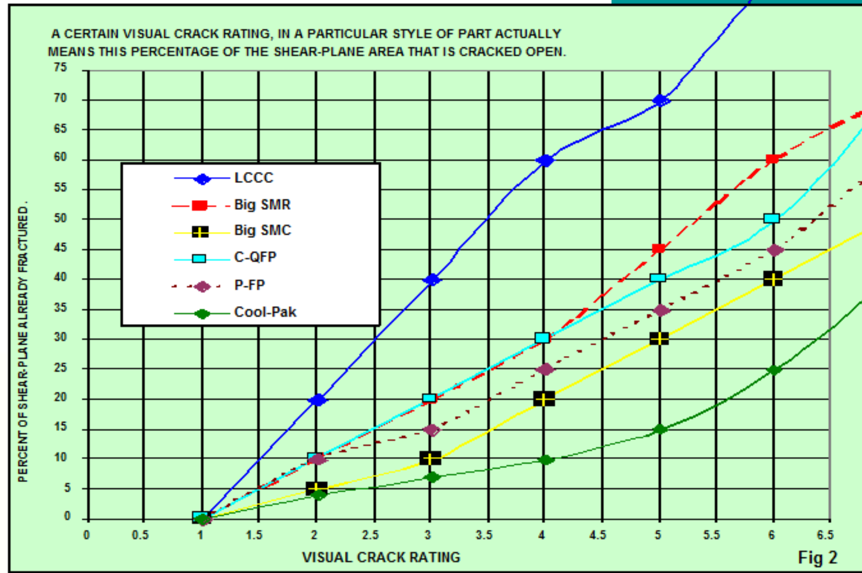
**This chart shows which common SMT components are likely to survive a typical LEO mission**

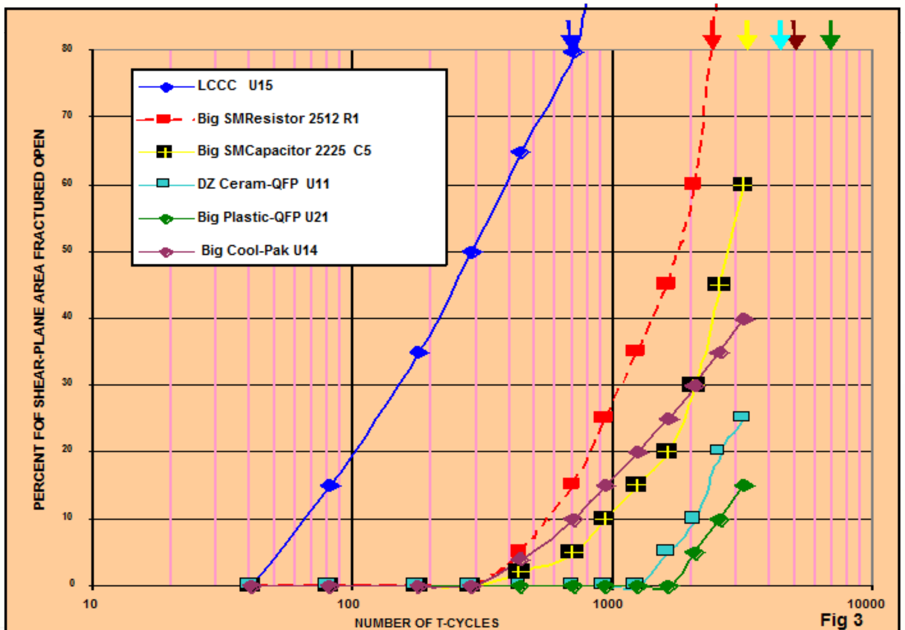


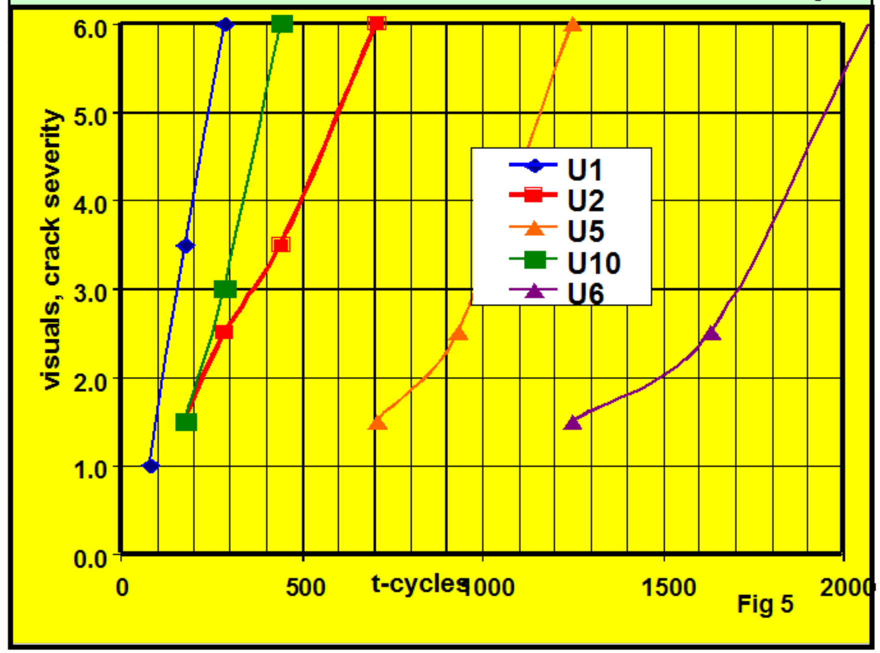

Cartoons, suggesting some of the hardware details necessary, when creating and using a predictor model. .

# APPENDIX C


INCREASING CRACK SEVERITY (VISUAL RATING) vs T-CYCLE EXPOSURE
VISUAL "CRACK SEVERITY"
LCCC U15
Big SMResistor 2512 R1
Big SMCapacitor 2225 C5
DZ Ceram-QFP U11
Big Plastic-QFP U21
Big Cool-Pak U14
Phase-1 F50
NUMBER OF "MILD" T-CYCLES (-10 C to + 125 C)
Fig 1


A CERTAIN VISUAL CRACK RATING, IN A PARTICULAR STYLE OF PART ACTUALLY MEANS THIS PERCENTAGE OF THE SHEAR-PLANE AREA THAT IS CRACKED OPEN.
PERCENT OF SHEAR-PLANE AREA ALREADY FRACTURED.
LCCC
Big SMR
Big SMC
C-QFP
P-FP
Cool-Pak
VISUAL CRACK RATING
Fig 2


PERCENT FOF SHEAR-PLANE AREA FRACTURED OPEN
LCCC U15
Big SMResistor 2512 R1
Big SMCapacitor 2225 C5
DZ Ceram-QFP U11
Big Plastic-QFP U21
Big Cool-Pak U14
NUMBER OF T-CYCLES
Fig 3


visuals, crack severity
U1
U2
U5
U10
U6
t-cycles
Fig 5