Reliability Test Plan Creation

Prove Reliability by Testing

PLOT Showcase
12 October 2023

Ronald Schop - Holland Innovative

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Introduction

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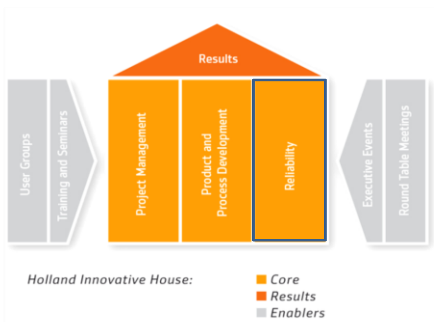

Ronald Schop
Sr. Reliability Specialist

- Reliability Competence Coach
- Strategic Projects at Customers
- Developing Reliability Academy
- User Groups, Seminars and Executive Events on Reliability

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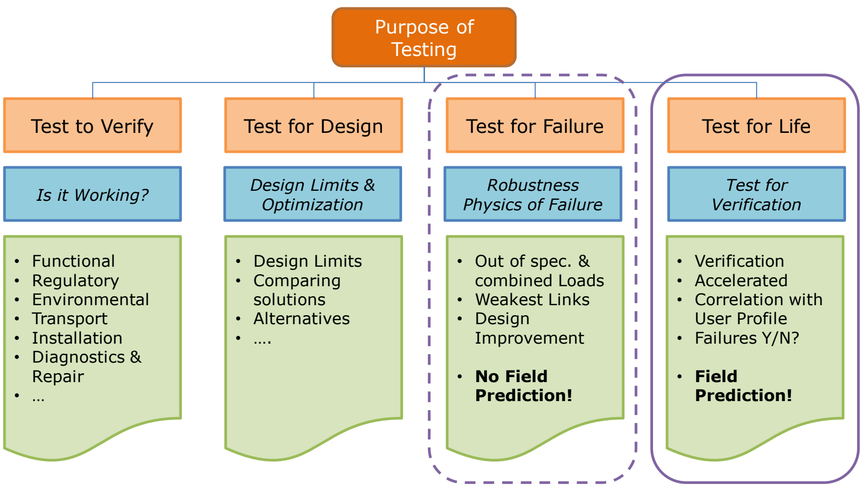
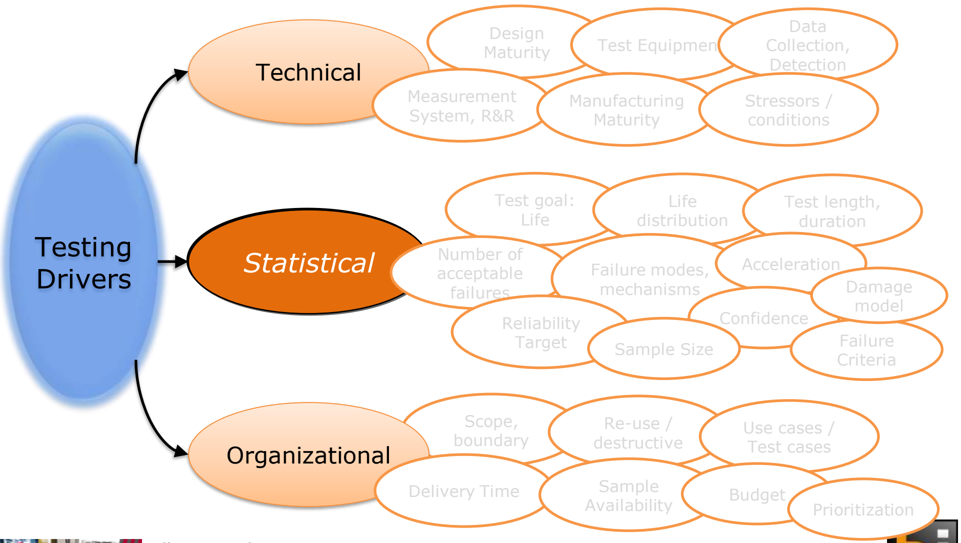
Content

1. **Reliability Testing Goals**
2. **Drivers in Reliability testing**
3. **Accelerated Life Testing**
4. **Types of Testing for Life**
5. **Reliability Test Plan Specification**

1 - Reliability Testing Goals



2 - Drivers in Reliability Testing



Illustrative listing, not intended to be complete

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3 - Accelerated Life testing

In all types of tests, we may use Acceleration Factors to reduce test-time

1. **Classical testing – No Acceleration**

2. **Accelerated Life Test - ALT**
   - Time compression
   - Stress acceleration

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Classical Reliability testing Not Accelerated

- **Advantages:**
  - No assumptions about acceleration models / factors
  - Real Life data – customer usage
  - All failure modes!
  - Including (subjective) customer feedback
  - No discussion about translation of results to field performance…

- **Drawback…**
  - Long testing times
  - Large sample sizes
  - Did we pick the "right" customers…?

Accelerated Life Test - ALT

1. Time compression
- Test more operating hours per day than in normal usage

2. Stress acceleration
- Test on a higher stress than in normal usage

Compress along TIME axis

- **Suitable for products used on continuous time basis**
  - Like tires, toasters, heaters, light bulbs …
- **Examples :**
  - Light bulbs : instead of the normal 6h/day increase to 24h/day
  - Tires : instead of 70 km /day seventy days of continuous use
  - Safety related aerospace components : 48000 take-off and landings ; perform in 6 days by compressing the time history and increasing the cycle frequency
- **No additional assumptions are needed … ?**

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Accelerate along STRESS axis

- **Suitable for products failing faster when**
  - **Older**…product 'ages' over time so fails faster in time
    - Time can be days, operational hours, mileage, cycles, etc.
  - **Stressed more**….increased stress leads to faster failures
- **Examples :**
  - Light bulbs : instead of the normal 3 Volt increase to 5 Volt stress
  - PCB : instead of normal 30 degr C increase to 70 degr C
  - Bearings : instead of normal 60 RPM increase to …
- **No additional assumptions are needed …?**

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For Accelerated Life Testing - ALT

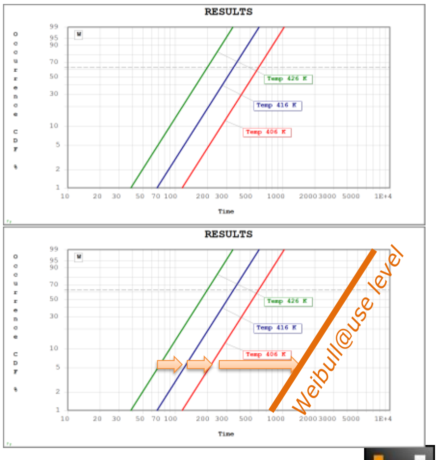
For setting-up and analyzing ALT you need 2 'models':

1. Life distribution:

- **Distribution** of 'Life' at **ANY** stress level.
- Models: Weibull, LogNormal, Exponential

2. Life-Stress model:

- Translate 'life' from any stress level to any **other** stress level
- Models: Statistical, Physics-Statistics, Physics-Experimental



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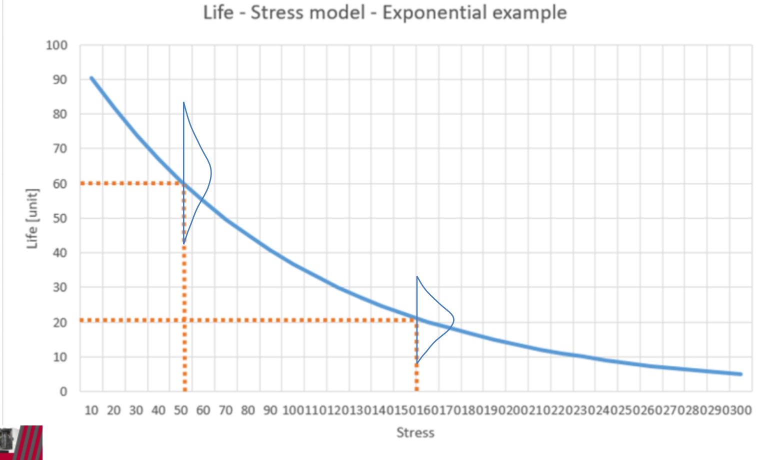
Life-Stress model - example

- **Life-Stress model:** translate 'Life' from any stress level to life at any other stress level



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Life-Stress models

- **Basic assumption:** the same failure mechanism is observed at normal use level and at the accelerated stress level
- So: **Identical failure mechanisms !**
  - e.g. Fatigue crack at normal use level (Field) and same crack in ALT at the higher stress level

- **Available life-stress models**
  1. Statistics-based models *(Weibull, Lognormal, Linear,…)*
  2. Physics-experimental based models *(Wohler, Black's,…)*
  3. Physics-statistics based models *(Arrhenius, Power Law, Coffin-Manson)*

4 - Test for Life/Reliability- 3 Types

1. **Quality Acceptance testing**
   - Zero failure testing = Fully Censored Testing
   - Zero-One failure testing

2. **Degradation testing**
   - Degradation MUST be measurable

3. **Testing with Failures**
   - To prove High Reliability Requirements
   - To assure / check we have the correct failure mechanism
   - To defining the Life-Stress model (e.g., SN curve)
   - Step Stress test = test to failure with known Life-Stress model

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Quality Acceptance testing

Zero/Zero-One failure = Binomial

Table 8-1. Success Testing Tables For Demonstrating Reliability and Quality

Number Of Tests With Zero Failures Allowed (1-confidence) = R^n

Reliability	Confidence Level (%)								
	50%	60%	70%	80%	90%	95%	99%	99.9%	99.99%
0.9999	6932	9163	12040	16094	23025	29956	46050	69075	92099
0.999	693	916	1204	1609	2302	2995	4603	6905	9206
0.998	347	458	602	804	1151	1497	2301	3451	4601
0.997	231	305	401	536	767	998	1533	2300	3066
0.996	173	229	301	402	575	748	1149	1724	2298
0.995	139	183	241	322	460	598	919	1379	1838
0.99	69	92	120	161	230	299	459	688	917
0.95	14	18	24	32	45	59	90	135	180
0.90	7	9	12	16	22	29	44	66	88
0.85	5	6	8	10	15	19	29	43	57
0.80	4	5	6	8	11	14	21	31	42
0.75	3	4	5	6	9	11	17	25	33
0.50	1	2	2	3	4	5	7	10	14

All fractions of the number of tests are rounded upward.

Number Of Tests With Up To One Failure Allowed (1-confidence) = $R^n + n(R^{(n-1)} * (1-R))$

Reliability	Confidence Level								
	50%	60%	70%	80%	90%	95%	99%	99.9%	99.99%
0.9999	16784	20223	24392	29943	38896	47437	66381	92331	117559
0.999	1679	2022	2439	2994	3889	4742	6636	9230	11751
0.998	839	1011	1219	1497	1944	2371	3317	4613	5873
0.997	560	674	813	998	1296	1580	2210	3074	3914
0.996	420	506	610	748	971	1185	1657	2305	2934
0.995	336	404	487	598	777	947	1325	1843	2346
0.99	168	202	244	299	388	473	662	920	1171
0.95	34	40	49	59	77	93	130	181	230
0.90	17	20	24	29	38	46	64	89	113
0.85	11	13	16	19	25	30	42	58	73
0.80	9	10	12	14	18	22	31	42	54
0.75	7	8	10	11	15	18	24	33	42
0.50	3	4	5	5	7	8	11	14	18

Zero failure test

Test time not equal to Life Requirement

$$R(t_o) = \exp\left[\frac{\ln(1-C)}{n\left(\frac{T}{t_o}\right)^{\beta}}\right] \quad or \quad R(t_o) = \exp\left[\frac{\ln(1-C)}{\sum_{i=1}^{n}\left(\frac{T_i}{t_o}\right)^{\beta}}\right]$$

$R(t_o)$ = reliability at time "t_o"
t_o = design life or reliability demonstration time
n = sample size
T = total test time of each part
β = Weibull shape parameter or Weibull slope
C = statistical confidence level specified

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RVP – Reliability Validation Plan Approach

Alternative to "Proving Reliability on 90% Confidence level" we can use the same formula to calculate the Confidence gained by all planned or completed tests.

$$C = 1 - R_{t0}^{\sum_{i=1}^{n}\left(\frac{T_i}{t_0}\right)^{\beta}}$$

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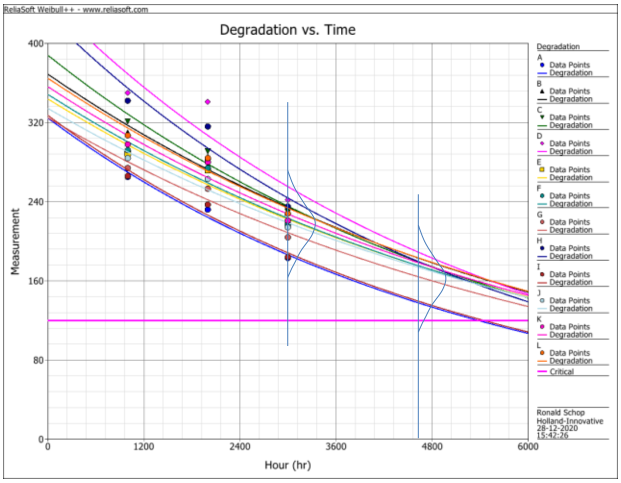
Degradation testing

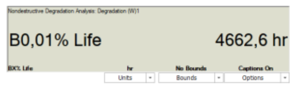
- **Pro's**
  – Reduce test times
  – Less Samples are required
  – Multiple observations, "failures", so no assumption of the distribution
- **Con's**
  – **Is there a measurable degradation parameter… ?**
  – Can we measure accurate enough?
  – What model to select for extrapolation?
- **Model is required for extrapolation… Typical models are;**
  – Linear – Archer's Law
  – Exponential
  – Power Law

Degradation Diagram (Lognormal/Exponential)



Vessel wall thickness reduction due to corrosion.

Requirement:
Max 0,01% may be lower than 120 mm.



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Testing with Failures for High Reliability Requirements

Zero Failure test plan for high Reliability requirements leads to very large sample sizes!

Number Of Tests With Zero Failures Allowed (1-confidence) = R^n									
	Confidence Level (%)								
Reliability	**50%**	**60%**	**70%**	**80%**	**90%**	**95%**	**99%**	**99.9%**	**99.99%**
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Stress tests with Arrhenius model

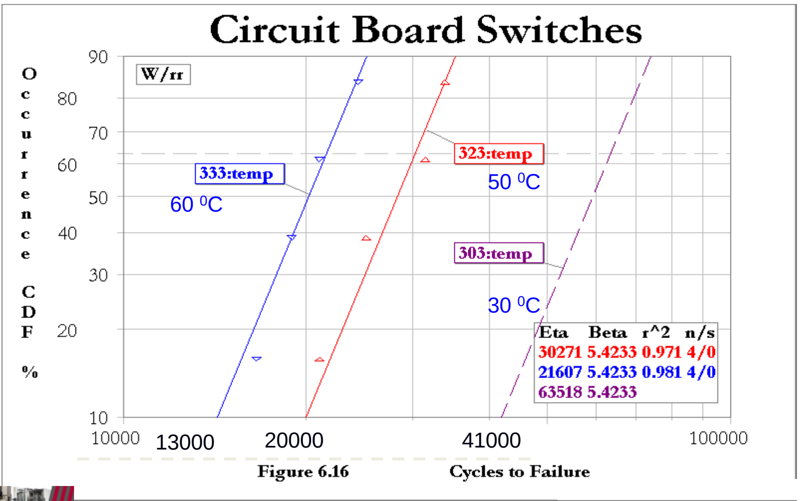

Figure 6.16

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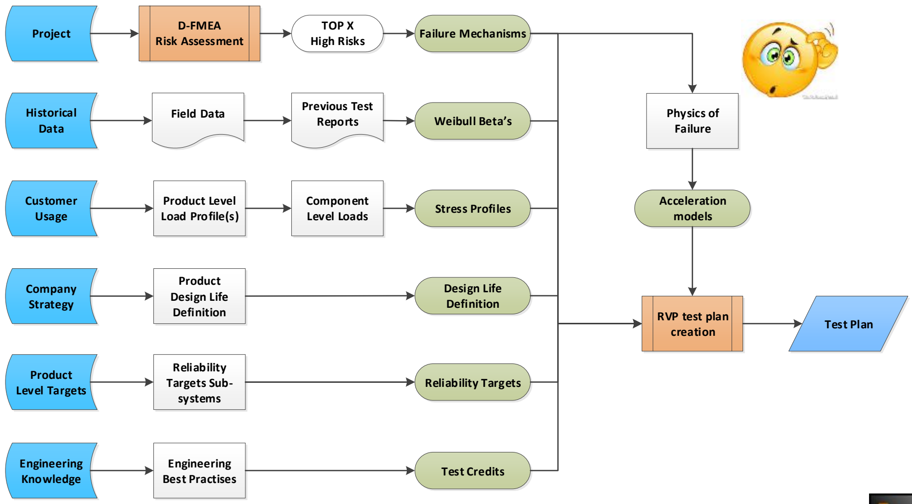
5 - Minimal content of a Reliability test specification
Simplified Test Plan Flowchart



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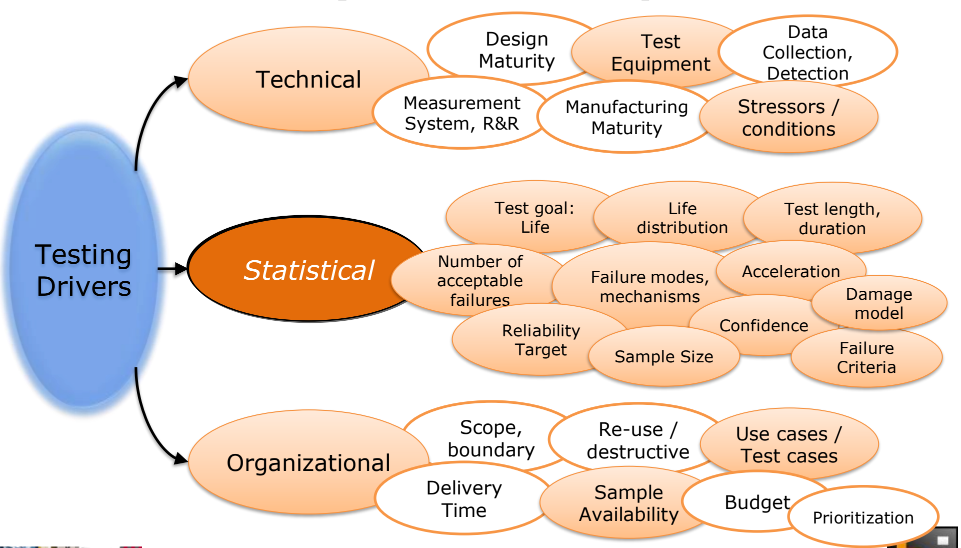
5 - Reliability Test Plan specification



Illustrative listing, not intended to be complete

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5 - Minimal content of a Reliability test specification

- **Subject under test.**
  - Product description and system boundaries.
- **Purpose of test.**
  - Type of test; Robustness, Life / Reliability

- **Design Life. Years, cycles, …**
- **Operating conditions. / Load distribution.**
  - Normal operation conditions.
  - Use cases / user conditions.
  - Usage distribution or 90^{th} percentile.
- **Set-up of test. (Test-rig design)**
  - Technical execution.
  - Environmental conditions.
- **Pass/Fail criteria.**
  - Incl. Measurement system / MSA.
- **Reliability requirement to be proven.**
- **Confidence level.**
- **Failure Mechanism under study – Physics of Failure.**
  - Single stress? Multiple stressors? How to combine?
  - How to deal when multiple modes are expected?
- **Life Distribution to be assumed, e.g. Weibull with Beta.**

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5 - Minimal content of a Reliability test specification

- **Type of Life Testing.**
  - Zero failure.
  - Degradation.
  - Test with failures.
- **Acceleration factors / Damage model.**
  - Time compression.
  - Stress increase – acceleration factor – ALT testing - Life stress model
  - Failure Model(s) to be assumed + model parameter(s)
- **Life-Stress model.**
  - Statistics-based (only statistics)
  - Physics-experimental based
  - Physics-statistics based.
- **How many failures are required.**
- **Sample size determination.**
  - How many samples. (e.g., to get sufficient failures within a limited amount of time)
  - Sample variation. (Random, select max/min, batches, ...)
  - Sample maturity. (Production method, serial quality, …
- **Communication during testing.**
- **Final inspection / damage pattern; what is to be measured, and how.**
- **Report Out**

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Thank you

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