Understanding Key Variables Impacting Reliability Demonstration Testing

ASQ Reliability and Risk Division Webinar Series
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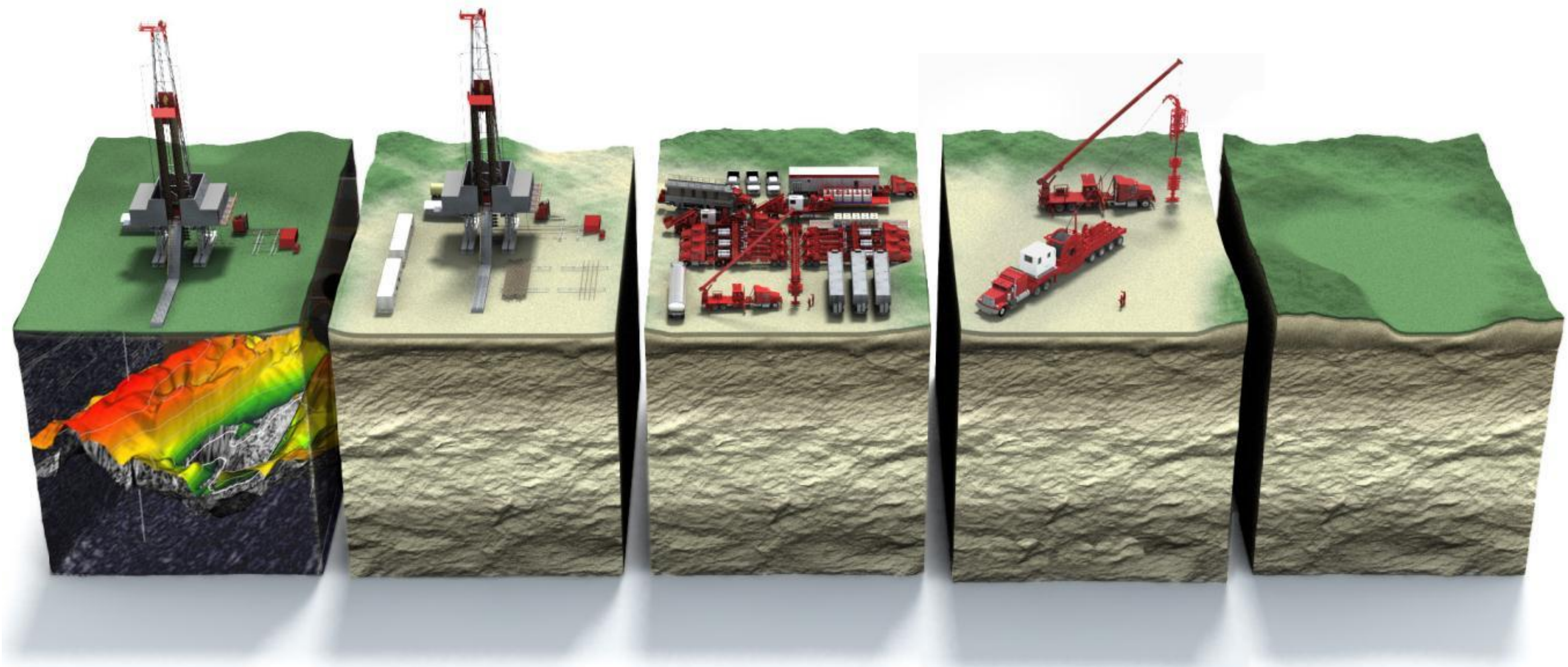
Outline

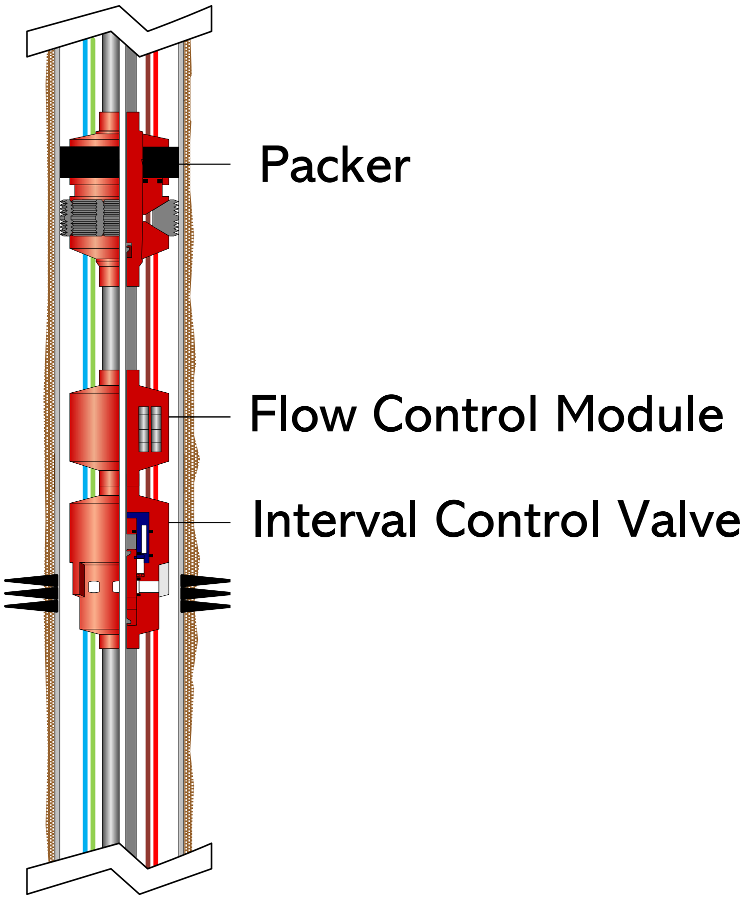
- Oil Field Life Cycle
- Introduction – Intelligent Completions
- Reliability Demonstration Testing
- Test Design Parameters
- Weibull Shape Parameter β
- Example 1 – Electronics Module
- Example 2 – Flow Control Module
- Lessons Learned

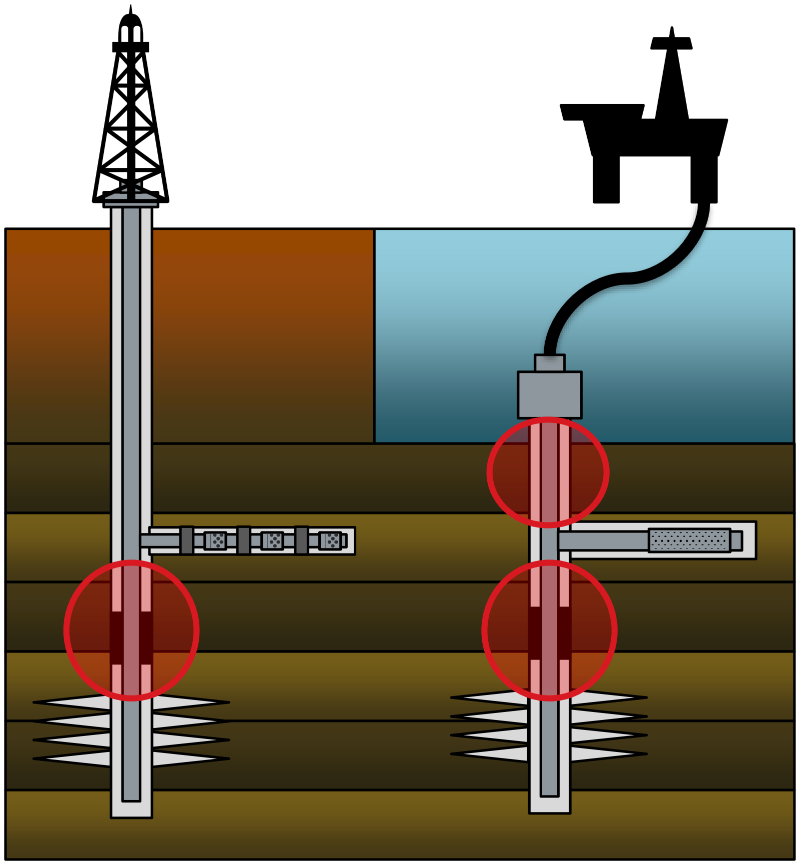
Oil Field Lifecycle



Exploration Well Construction Completion Production Abandonment

Intelligent Completions

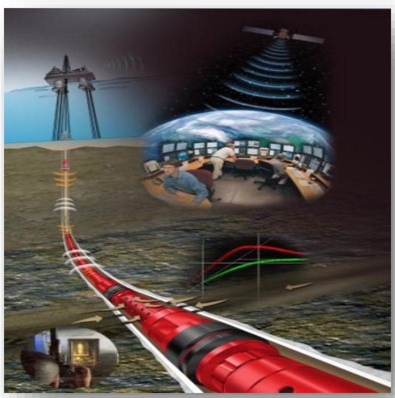


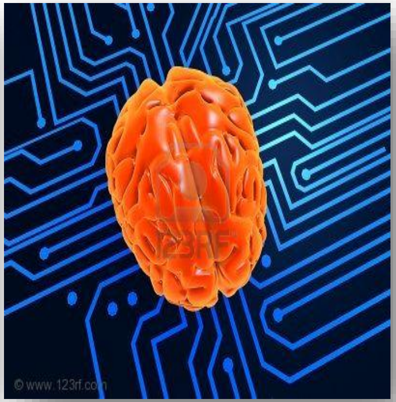


Fit-for-purpose permanent monitoring & flow control systems enable optimized production without costly well intervention

Application and Benefits

Real-time permanent monitoring of downhole conditions ▶ Obtain continuous pressure and temperature data ▶ Single and multi-zone monitoring applications ▶ Help increase productivity through the life of the well





Permanent monitoring systems can be used in any application such as deepwater, unconventional, mature fields or HP/HT

Reliability Demonstration Test

- Product validation program set up as success testing.
- Helps demonstrate a minimum level of product reliability.
- N test specimens are tested with the goal of observing N or (N-1) successes.

X X X X

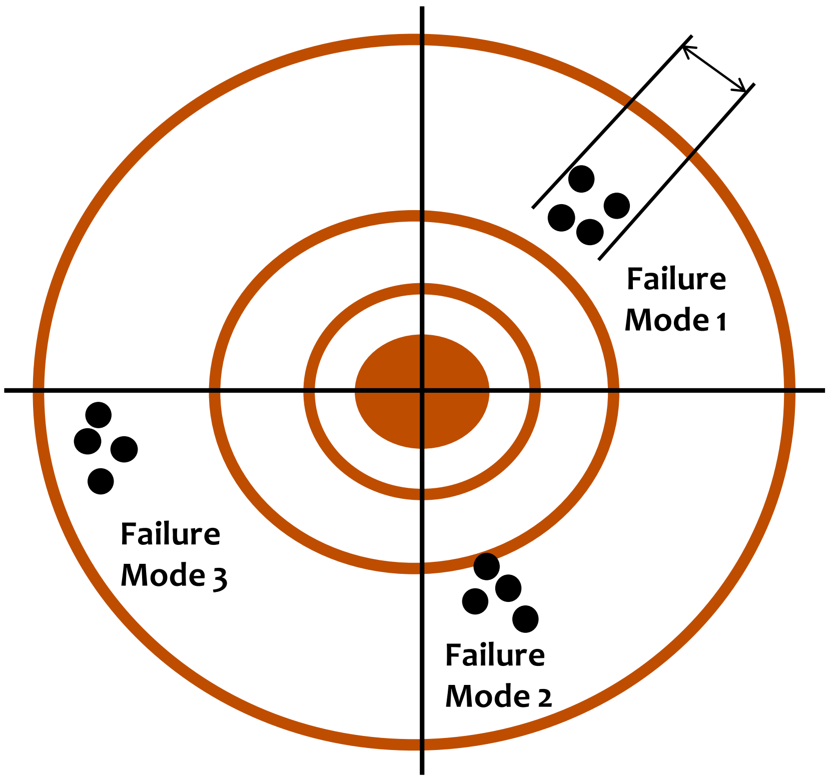
Test Conditions

<u>No failures</u>

Test conditions simulate one mission life of the product

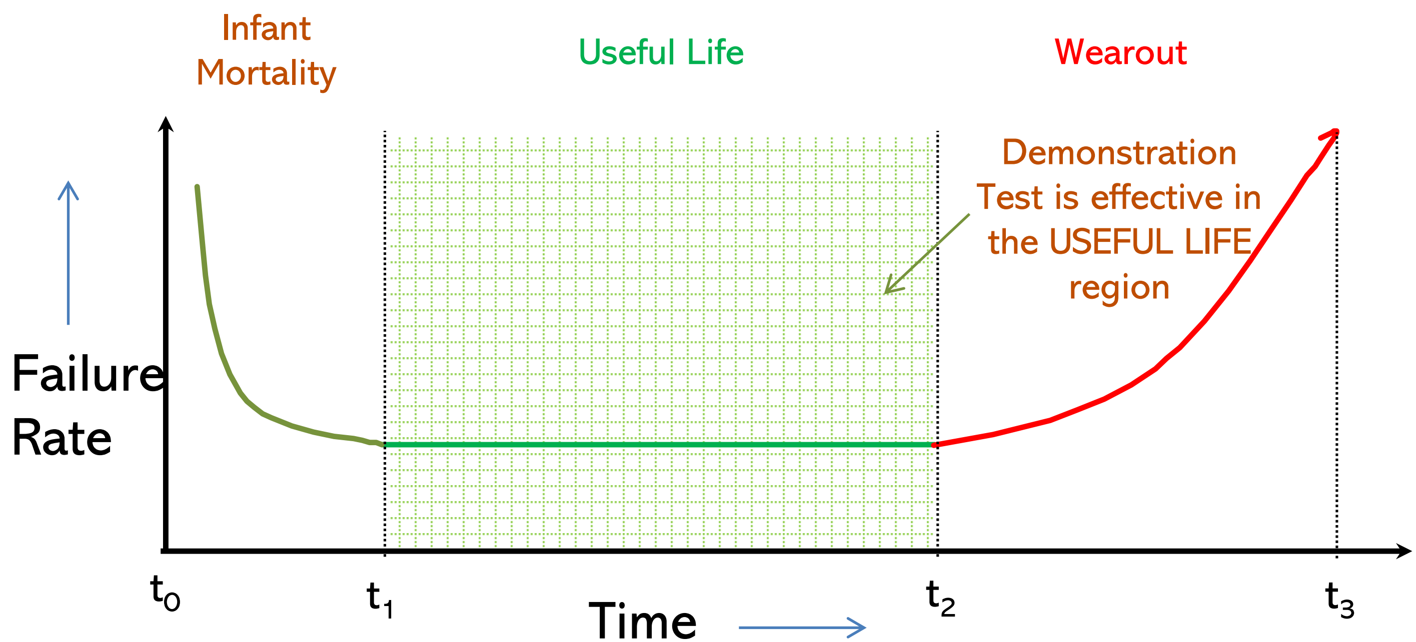
Reliability Demonstration Test (2)

- RDT are designed for underlying failure mode.
- Each failure mode and mechanism needs to be targeted individually based on the applied test stress.
- Resembles a shooting dart where all targets are required to be shot down



Shooting dart analogy to reliability demonstration test

Reliability Demonstration Test (3)



RDT is effective in demonstrating useful life of the product

Reliability Demonstration Test Approach

Step 1 – Reliability Specifications

Determine expected levels of reliability, confidence and lifetime to be demonstrated.

Step 2 - Life Time Stresses

Identify product lifetime stresses. Use of FMEAs, prior knowledge, etc.

Step 3 – Acceleration Factor Model

Determine acceleration factor model which explains the life-stress relationship of the product.

Step 4 – Accelerated Stress Levels

Determine adequate accelerated stress level which results in high probability of test success.

Step 5 – Design

Optimize sample size and test time for the given levels of reliability, confidence and lifetime.

Focus is on Parametric RDT design approach with Acceleration

Parametric Cumulative Binomial Model

$$1 - \mathrm{CL} = \sum_{i=0}^{f} \frac{n!}{i!.\,(n-i)!}.\,(1 - R_{Test})^{i}.\,{R_{Test}}^{n-i} \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

Parametric binomial formulation is used when expected test time is different from the time when reliability is evaluated.

For Weibull distribution

$$R_{Test} = e^{-\left(\frac{t_{Test}}{\eta}\right)^{\beta}} \qquad \ldots\ldots\ldots\ldots\ldots (2)$$

- R_{Test} = Reliability at test
- t_{demo} = Expected lifetime
- CL = Confidence level

$$\eta = \frac{t_{demo}}{\left(-\ln(R_{Demo})\right)^{\frac{1}{\beta}}} \qquad \ldots\ldots\ldots\ldots\ldots (3)$$

$$1 - \mathrm{CL} = \sum_{i=0}^{f} \frac{n!}{i!.(n-i)!} \times \left(1 - e^{-\left(\frac{t_{test}}{\eta}\right)^{\beta}}\right)^{i} \times \left(e^{-\left(\frac{t_{test}}{\eta}\right)^{\beta}}\right)^{n-i} \qquad \ldots\ldots\ldots\ldots\ldots (4)$$

Multiple test design parameters impact reliability test design

RDT Design Parameters

#	Parameter	Category	Description
1	Product Reliability	Constant	Specified by end user
2	Operating Lifetime	Constant	Specified by end user
3	Confidence Level	Constant	Specified by end user
4	Sample Size	Variable	Optimized in test design
5	Acceleration Factor	Constant	Based on prior knowledge
6	Acceptable # of Failures	Constant	Test decision criteria
7	Shape Parameter	Variable	Based on prior knowledge
8	Test Time	Variable	Optimized in test design

Test design parameters can be classified in two major categories

RDT Design Parameters (2)

End User Requirements

Reliability	Confidence	Lifetime

↓

Design Constraints

Acceleration Factor	# of Acceptable Failures

↓

Approximation based on Prior Knowledge

Shape Parameter

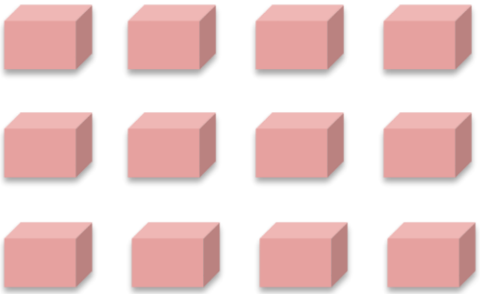
↓

Trade-Off

Sample Size	Test Time

RDT Design Classification

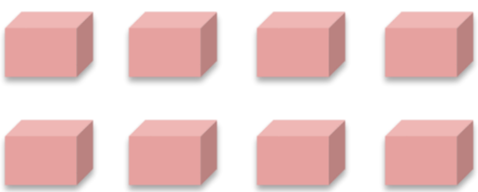
Sample Size = S1



$t=0$ $t=t_1$

Short test time with large sample size

Sample Size = S2 < S1



$t=0$ $t=t_2$

$t_2 > t_1$

Sample Size = S3 < S2

$t=0$ $t=t_3$

$t_3 > t_2$

Long test time with small sample size

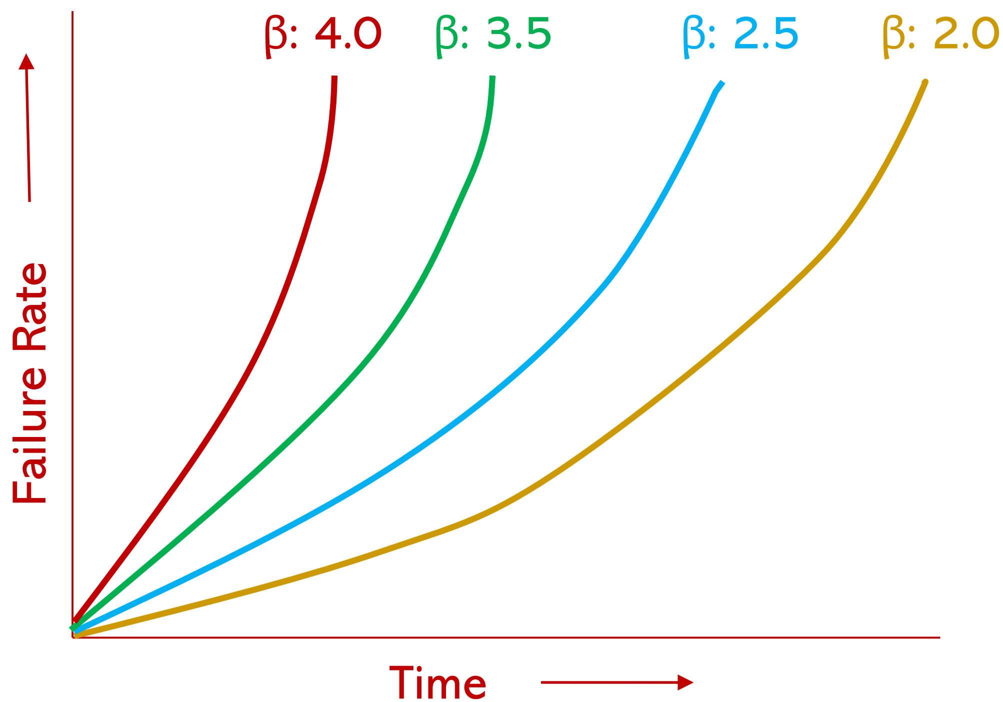
Optimizing RDT design based on sample size and test time

Weibull Shape Parameter, β

- Product failure rate increases with increase in Weibull shape parameter 'β'.

- Higher value of Weibull shape parameter 'β' relates to high number of expected failures in given time.

- Product with <u>higher</u> Weibull shape parameter 'β' results in relatively <u>short</u> test time.



Forward behavior of Weibull shape parameter

Example 1 – Electronics Module

- 80% R for 10 Yrs. lifetime at 185°C (60% lower confidence)
- Test Temperature: 215°C, Acceleration Factor: 3.48
- Sample Size: 20, Weibull Shape Parameter β: 1.0 – 1.2

	Test Time, Yrs.					
Beta	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**
1.0	53.97%	78.81%	90.25%	95.51%	97.93%	99.05%
1.2	42.12%	71.53%	87.04%	94.42%	97.70%	99.09%
1.4	31.98%	63.83%	83.37%	93.17%	97.45%	99.12%
1.6	23.78%	56.10%	79.30%	91.76%	97.17%	99.16%
1.8	17.42%	48.65%	74.91%	90.18%	96.88%	99.19%
2.0	12.62%	41.70%	70.30%	88.45%	96.57%	99.22%

Change in confidence level over the range of test time and Weibull β

Example 1 – Electronics Module (2)

$$t_{critical} = \frac{\text{Lifetime}}{\text{Acceleration Factor}} = \frac{10}{3.48} = 2.87 \quad \dots\dots\dots\dots\dots (5)$$

	Test Time, Yrs.					
Beta	**0.5**	**1.0**	**1.5**	**2.0**	**2.87**	**3.0**
1.0	53.97%	78.81%	90.25%	95.51%	**98.85%**	99.05%
1.2	42.12%	71.53%	87.04%	94.42%	**98.85%**	99.09%
1.4	31.98%	63.83%	83.37%	93.17%	**98.85%**	99.12%
1.6	23.78%	56.10%	79.30%	91.76%	**98.85%**	99.16%
1.8	17.42%	48.65%	74.91%	90.18%	**98.85%**	99.19%
2.0	12.62%	41.70%	70.30%	88.45%	**98.85%**	99.22%

Backward Behavior (test times 0.5–2.87)

Forward Behavior (test time 3.0)

Weibull β changes its behavior at test time equals to t-critical

Example 1 – Electronics Module (3)

- Sample Size: 20, Weibull Shape Parameter β: 1.0 – 1.2

#	Test Case	1	2
1	Reliability	80%	80%
2	Lifetime, Yrs.	10	10
3	Confidence	60%	60%
4	Sample Size	20	20
5	AF	3.48	3.48
6	t-critical, Yrs.	2.87	2.87
7	Weibull Beta	**1.0**	**1.2**
8	Test Time, Yrs.	**0.59**	**0.77**

Higher Weibull β provides conservative test design for large sample size with short test time

Example 2 – Flow Control Module

- 96.5% R for 15 Yrs. lifetime for 1 grms (90% lower confidence)
- Test Vibration: 12 grms, Acceleration Factor: 54,652
- Sample Size: 2, Weibull Shape Parameter β: 2.5 – 2.7

	Test Time, Hrs.					
Beta	1.0	2.0	4.0	6.0	8.0	10.0
2.0	1.23%	4.81%	17.90%	35.84%	54.56%	70.85%
2.2	1.03%	4.64%	19.62%	41.30%	63.33%	80.59%
2.4	0.86%	4.48%	21.48%	47.26%	72.08%	88.69%
2.6	0.73%	4.32%	23.48%	53.61%	80.27%	94.49%
2.8	0.61%	4.17%	25.65%	60.24%	87.30%	97.88%
3.0	0.51%	4.02%	27.97%	66.96%	92.76%	99.41%

Change in confidence level over the range of test time and Weibull β

Example 2 – Flow Control Module (2)

$$t_{critical} = \frac{\text{Lifetime (Hrs.)}}{\text{Acceleration Factor}} = \frac{15 \times 8760}{54652} = 2.40 \quad \text{..............} (6)$$

	Test Time, Hrs.					
Beta	1.0	2.0	2.4	6.0	8.0	10.0
2.0	1.23%	4.81%	6.88%	35.84%	54.56%	70.85%
2.2	1.03%	4.64%	6.88%	41.30%	63.33%	80.59%
2.4	0.86%	4.48%	6.88%	47.26%	72.08%	88.69%
2.6	0.73%	4.32%	6.88%	53.61%	80.27%	94.49%
2.8	0.61%	4.17%	6.88%	60.24%	87.30%	97.88%
3.0	0.51%	4.02%	6.88%	66.96%	92.76%	99.41%

Backward Behavior

Forward Behavior

Weibull β changes its behavior at test time equals to t-critical

Example 2 – Flow Control Module (3)

- Sample Size: 2, Weibull Shape Parameter β: 2.5 – 2.7

#	Test Case	1	2
1	Reliability	96.5%	96.5%
2	Lifetime, Yrs.	15	15
3	Confidence	90%	90%
4	Sample Size	2	2
5	AF	54652	54652
6	t-critical, Hrs.	2.4	2.4
7	Weibull Beta	**2.5**	**2.7**
8	Test Time, Hrs.	**9.65**	**8.71**

Lower Weibull β provides conservative test design for small sample size with long test time

Test Time and t-critical

#	Test Time < t-critical	Test Time > t-critical
1	Short test time with large sample size	Long test time with small sample size
2	Reliability demonstrations are based on large amount of data early in life	Reliability demonstrations are based on small amount of data at end of life
3	Unknown wear-out failure modes may occur later in life	Defect-related (manufacturing / assembly processes) failures might not show up in the small sample
4	Higher value of Weibull shape parameter β results in conservative test design	Lower value Weibull shape parameter β results in conservative test design

RDT Learnings

Benefits

- RDT enables to quantify the lower bound of achieved reliability based on test performance.
- It generally requires small sample size and shorter test times compared to ALT.

Drawbacks

- Limited sample size, at times, is too small to provide a chance for each failure mode to manifest.
- Unfair trade-off between sample size and test time may reduce the potential of catching failures due to small sample size.

Thank You

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