# Naval Undersea Warfare Center

# Division Keyport

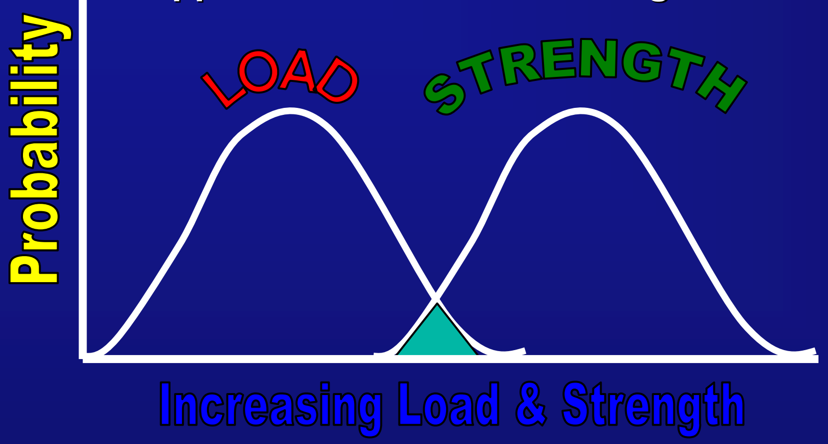
June $15^{th}$, 2005

## Durability Assessment using Accelerated Life Testing

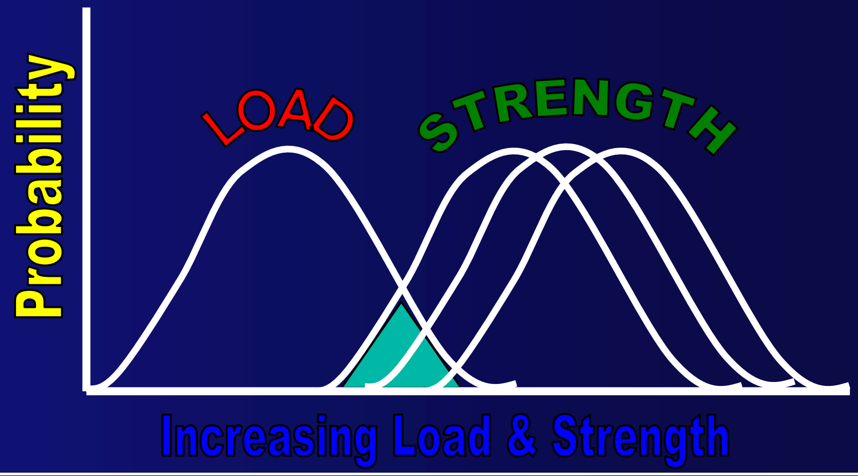
Mr. Gary Zook
(360) 396-1217
gzook@ kpt. nuwc. navy. mil

# Accelerated Life Testing

## Things Fail When Applied Load Exceeds Strength



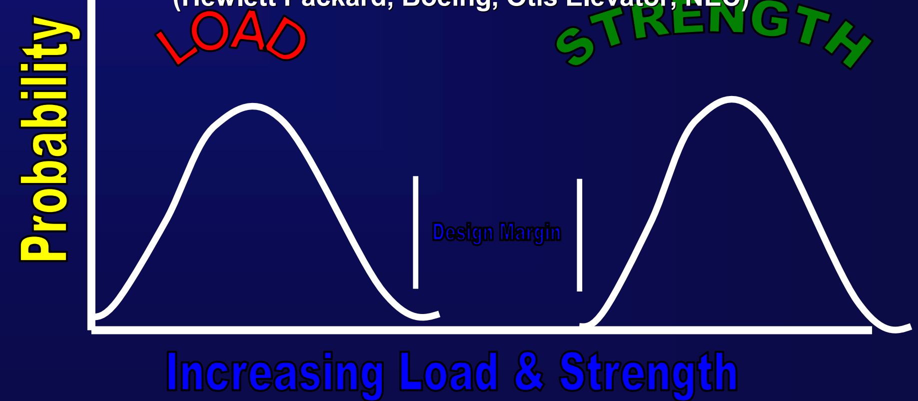

## Product Strength Degradation with Time




## Time Compression via Increasing Stresses


## Result is Reliable Design

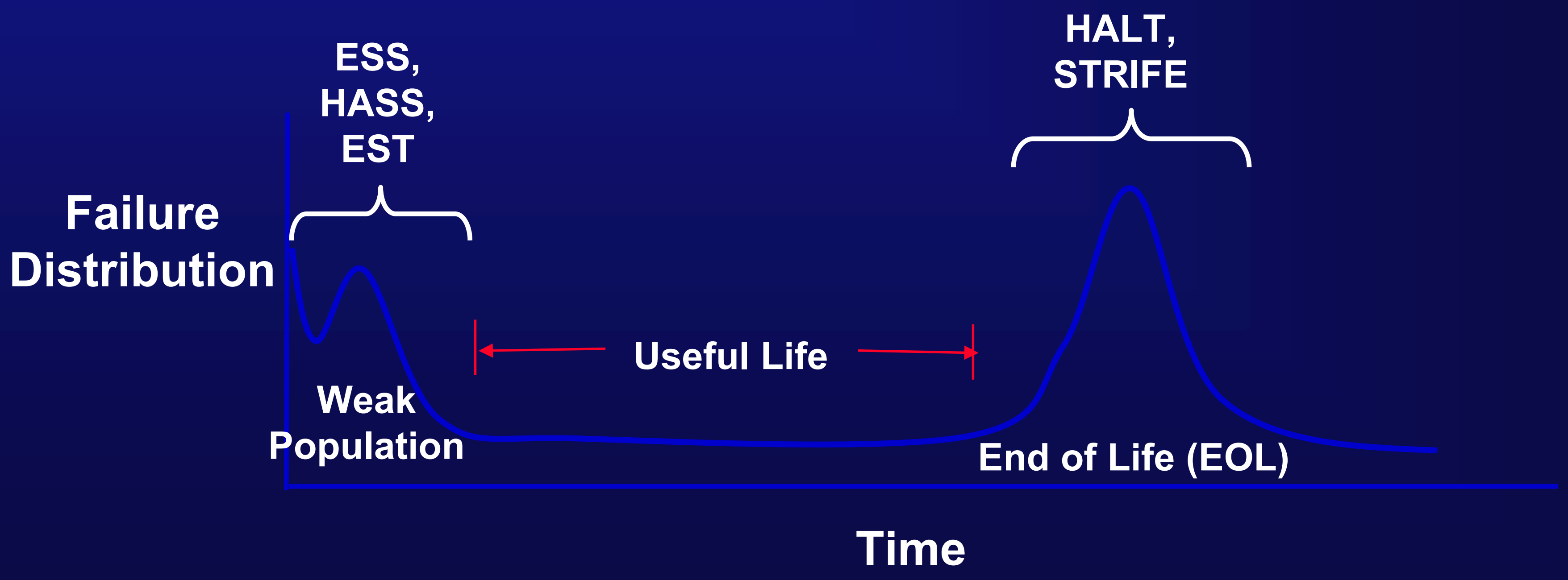
(Hewlett Packard, Boeing, Otis Elevator, NEC)



# Accelerated Life Testing

- Highly Accelerated Life Testing (HALT)
  - Test to Failure (little concern about real environment)
  - Should be part of Design Effort
  - Industry has found this the most cost effective
- Highly Accelerated Stress Screening (HASS)
  - Non-Destructive
  - Removes Latent Defects
  - Test Levels determined from HALT
  - Can Migrate to Highly Accelerated Stress Audit (HASA)
- Environmental Stress Screening (ESS)
  - Non-Destructive
  - Removes Latent Defects
  - Typically based on Handbooks
- Environmental Stress Test (EST)
  - System Level ESS
  - Tested within Spec Levels
- Stressful Life Test (STRIFE)
  - Durability Assessment
  - Acceleration of Real Life Environments

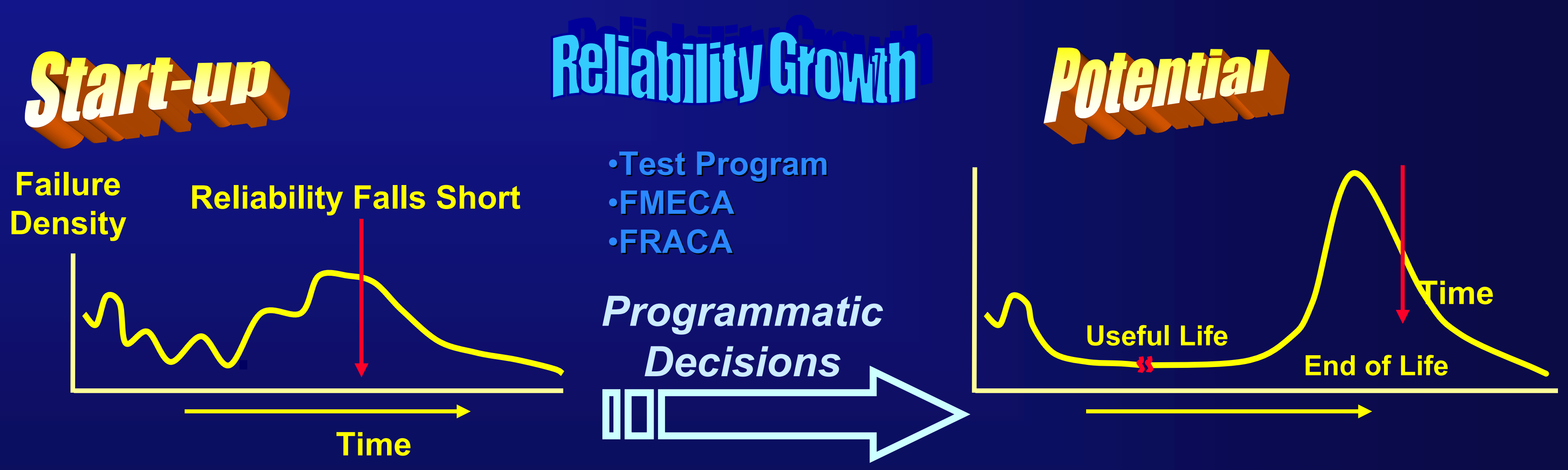
# Failure Distribution Model



Undersea Warfare Center Division

# Accelerated Life Testing

## Failure Distribution Model




**Assume Tests Failures are Systemic Until Proven Otherwise**

# STRIFE Example (Durability Testing)

## What is expected MTBF?

- Existing electromechanical Gyros replaced with solid state technology
- Existing MTBF 600 hours
- Calculated new MTBF 44,000 hours

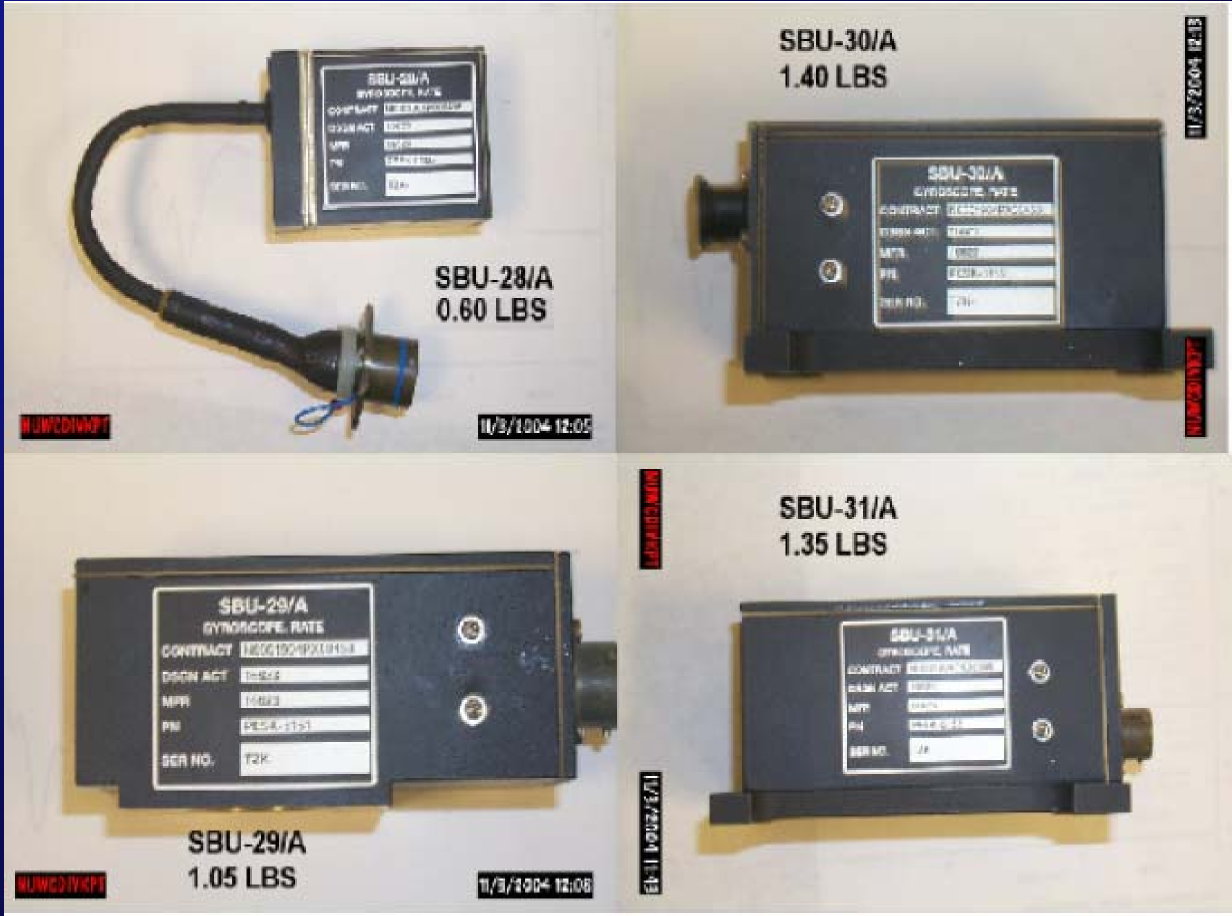


Figure 1. All Rate Gyros with weights

# STRIFE Testing

- STRIFE (stressful life) is an approach to determine durability
- Goal was to simulate 44,000 hours of operation
- For Vibration:
  - MIL-STD-810F Fatigue Relationship
    - Inverse Power Equation

$$\left(\frac{W_0}{W_1}\right) = \left(\frac{T_1}{T_0}\right)^{\left(1/M\right)}$$

$W_0$: Baseline Vibration Level
$W_1$: Test Vibration Level
$T_0$ : Baseline Time
$T_1$ : Test Time
M : Material Constant

| Material Constant Ranges from: | |
|---|---|
| Kipp Company Paper M=2 (random Vib) | |
| MIL-S-810 | M=4-6 |
| D.S. Steinburg | M=6.4 |

For this example:
$W_0$= 4.2 g's RMS
$T_0$ = 44,000 hours
$T_1$ = 250 hours
M = 4 (connectors)

$W_1$ = 15.2 g's RMS

# STRIFE Testing

- For Thermal:
  - Min and Max temps based on HALT
    - -75F and 175F
  - Ramping and dwell times based on equipment capability and functional test requirements
  - MIL-H-344 used for acceleration factor

$$D = N * S^{B}$$

D is Damage Index
N is Cycles
S is delta Temperature
B is Fatigue exponent (2.5 for solder)

For this example:
N = 750 test cycles
S = 250 delta F
D= 7.41e8

If actual environment is S=80 delta F:
D= 7.41e8 (same effective damage index)

***N=12944 cycles for actual environment***

# STRIFE Testing

**Combined Vibration and Thermal Testing with Liquid Nitrogen Assist**

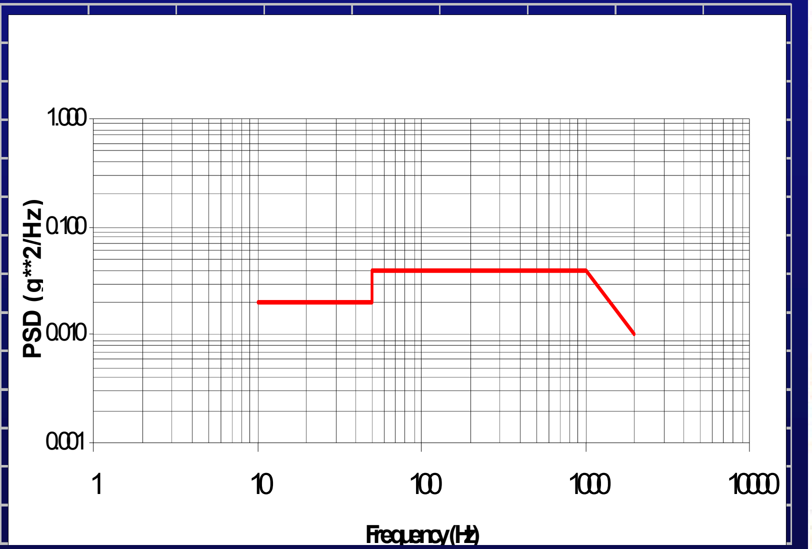



Figure 13. STRIFE Test Setup Example

# STRIFE Testing

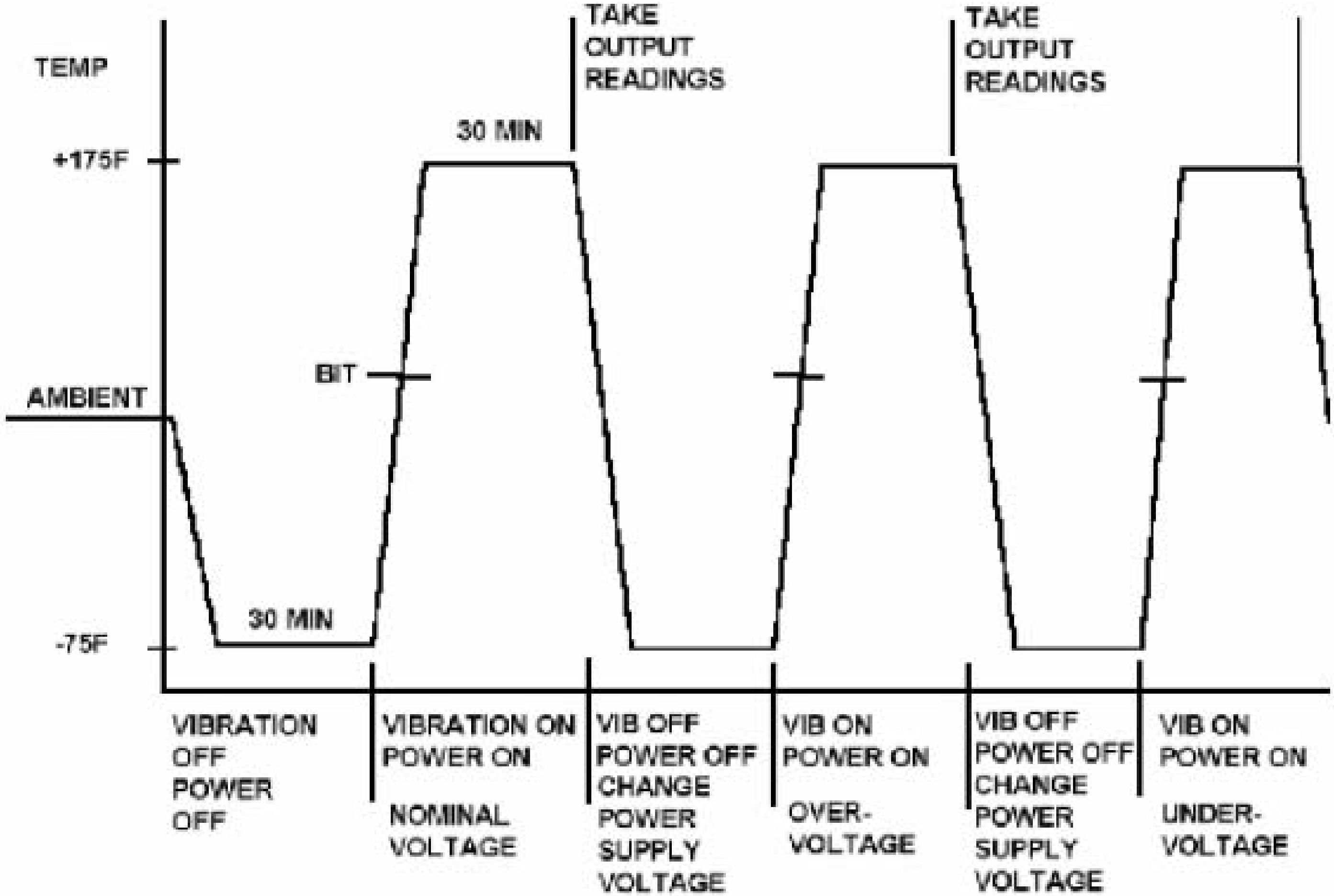



Figure 14. STRIFE profile (one complete cycle)

# STRIFE Analysis

- Using Assurance Tables from "Statistical Design and Analysis of Engineering Experiments", *Lipson and Sheth*, 1973, McGraw-Hill

For a sample of two with no failures:

Vibration: 86.5% *Assurance* population will survive 44,000 hours at 4.2 g's
*or* 99.8% *Assurance* population will survive 14,667 hours at 4.2 g's

Thermal: 86.5% *Assurance* population will survive 12944 cycles at 80 delta F
*or* 99.8% *Assurance* population will survive 4315 cycles at 80 delta F

For comparison, one sample with no failures would give 63.2% assurance at 44,000 and 95.0% assurance at 14,667 for vibration

Assumption is that test samples adequately represent population

# STRIFE Testing – UUV Example

- Real Environment
  - 0.5 G's
  - 2000 hours of Operation

$$\left(\frac{W_0}{W_1}\right) = \left(\frac{T_1}{T_0}\right)^{\left(1/M\right)}$$

$W_0$: Baseline Vibration Level
$W_1$: Test Vibration Level
$T_0$ : Baseline Time
$T_1$ : Test Time
M : Material Constant = 6 (general case)

**Limit Test Vibration to 3 G's**

$W_1$ = 3.0 g's RMS
$W_0$ = 0.5 g's RMS
$T_0$ = 2000 hours
$T_1$ = ? hours

$T_1$ = 1.54 Test Hours

# Closing Thoughts

- **Navy (DoD?) Environmental Test labs designed around 1960's technology and equipment**
  - **Steady state environments**
  - **Single axis vibration**
  - **Requirements based test design**

- **My Approach:**
  - **Upgrade equipment**
    - **Multi-axis vibration**
    - **High performance thermal systems (LN2)**
  - **Continue our education of accelerated life testing (HALT/HASS/STRIFE/ESS)**

**NAVSEA Keyport's 3-Axis Electro-dynamic Vibration Test System**

***Accelerated Life Testing is part of an Effective T&E approach***