Missile Life Extension (MLE)
Accelerated Storage Life Test (ASLT)

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MLE Program Summary

• Study Goal
  – Define additional missile component replacement, maintenance, or refurbishment needed related to Recertification of missiles which will be in service beyond 30 years of natural age

• MLE Program consists of two main elements:
  – Component Life Analysis on all Missile components based on available data extrapolated to 45 year life
    • Many analyzed components are carried into the follow-on designs

• Forebody / Control Section Assembly (CSA) Accelerated Life Testing
  – Temperature Cycling, Vibration and Shock to simulate 22 years of additional life on the provided Government Furnished Equipment (GFE)
Task Description

• Storage life of missiles was considered to be 30 years
  – At the end of the storage period, most of the missiles are found in good working condition

• Great savings of resources and material cost would result if the missiles would be found capable of surviving a much longer storage period – current storage duration extended by 10 years
  – A program containing multiple activities, analyses and tests has been undertaken
  – A considerable part of this program was performance of an accelerated reliability demonstration test to demonstrate missile capability to withstand 45 years of storage
  – If successful, the missiles could be stored for 45 years and be fully operational
  – Reliability Goal was based upon XX out of 100 missiles operational after the storage
Accelerated Storage Life Test Plan

• Accelerated Storage Life Test (ASLT) objective
  – Estimate probability of survival as a function of storage duration for up to 45 years
    • Simulates cumulative damage produced by storage and transportation stresses during and up to extended storage life
  – Recommend measures necessary to extend storage life up to 45 years

• Accelerated Testing - Temperature:
  – Extend received GFE life to forty-five years of climatic stresses via thermal cycling and thermal exposure
  – High and Low temperatures and number of cycles selected to simulate cumulative damage

• Accelerated Testing - Vibration/Shock:
  – Extend received GFE life to forty-five years of transportation/handling stresses
    • 50,000 miles of transportation vibration
    • Vibration: Truck (fixed cargo)
    • Shock: Handling
Physics of Failure Approach

• Determine environmental and dynamic stresses on missiles during the storage period
  – During storage period, besides being stored, the missiles are transported using different means of transportation, loaded and unloaded
  – The four main stresses are therefore:
    • Thermal exposure to high and low temperatures
      – Diurnal in cold and hot climate
      – Nocturnal in hot and cold climate
    • Thermal cycling
      – Between the diurnal and nocturnal temperatures
    • Transportation vibration
    • Drop shock
• Reliability allocated to each of the four stresses: $0.YY = (0.XX^{1/4})$
Transforming Thermal Use Profiles into One

• Transform all high temperature exposures into one high level
  – The temperature levels higher than freezing of nocturnal and lower diurnal temperatures will be normalized to the level of the higher diurnal temperature using Arrhenius thermal relationship.
  – This final temperature will be accelerated in test and its overall duration will be distributed over the high temperature period of the thermal cycling

\[
t_{H_{\text{Total}}} = t_H + \sum t_i \cdot e^{- \frac{E_a}{k_B} \left( \frac{1}{T_i+273} - \frac{1}{T_H+273} \right)}
\]

• Low temperature exposure
  – The temperatures in arctic climate corresponding to freezing temperatures will be normalized to the lower nocturnal temperature, its stress accelerated by applying a significantly lower low test temperature.
  – This exposure will also be distributed over the determined number of test thermal cycles

\[
t_{L_{\text{Total}}} = t_L + \sum t_i \cdot e^{- \frac{E_a}{k_B} \left( \frac{1}{T_i+273} - \frac{1}{T_L+273} \right)}
\]
Thermal Cycling, Vibration and Handling Drop

• Thermal Cycling
  – The overall number of thermal cycles will be equal to the number of diurnal/nocturnal cycles over the storage period. For Y years of storage, the number of thermal cycles is:
    – $N_{TC}(Y) = 365 \times Y$
    – $N_{TC}(45) = 16,425$ thermal cycles

• Vibration Exposure
  – Vibration stress is applied through transportation of the missiles in trucks. Requirements are as follows:
    • Duration: 50,000 miles total
    • Vibration level: as described in MIL-STD-810G, for the secured load transportation [Root mean square acceleration (GRMS)]

• Handling Shock
  – It can be conservatively assumed that a missile is dropped during the following operations:
    – Transportation loading = 2 times total
    – Assumed average number of test handling in life = 6 times total
Accelerated Storage Life Test Design

• Total missile reliability in storage is the product of its reliability regarding each of the stresses:

\[ R_{\text{Item}}(\text{Stress}, t_0) = \prod_{i=1}^{S} R_{\text{Item}}(\text{Stress}_i, t_i) \]

• \( S \) = number of stresses
• \( t_0 \) = time for reliability calculation (may be between the scheduled maintenances)
• \( t_i \) = duration of time in each individual stress

• Reliability is allocated (for simplicity) to each of the stress as:

\[
R_{\text{Item}}(t_0) = \left( R_{\text{Stress}_i}(t_i) \right)^S \\
R_{\text{Stress}_i}(t_i) = \frac{S}{\ln \left( R_{\text{Item}}(t_0) \right)}
\]

• Average failure rate or failure frequency is then:

\[
\lambda_{a, \text{Missile}}(\text{Stress}, t_0) = -\frac{\ln \left[ R_{\text{Missile}}(\text{Stress}, t_0) \right]}{t_0}
\]

• The test is to be designed to determine the following:
  – Reliability or probability of missile being capable to accomplish its expected mission up to the end of 45-year storage time.
  – Expected life of the limited life items
  – Maintenance actions necessary for realization of the missile probability of survival for the desired storage period.
Accelerated Storage Life Test Design

• To validate reliability, the test duration needs to exceed the required life (45 years) so that the test duration is: \( k \times t_0 \)

  – Multiplier \( k \) is determined from the reliability requirement (IEC 62506):

    \[
    R_i(t_0, k, \mu_{L_i}) = \Phi \left[ \frac{k - 1}{\sqrt{(a \cdot k)^2 + (b)^2}} \right]
    \]

• Where:

  • \( a, b \) = multipliers for the respective mean strength and load cumulative degradation values (non accelerated stress durations) to obtain the respective standard deviations

  – Reliability curve is plotted as a function of variable \( k \), and its required value is then determined from the required reliability

  – Failure rate in the accelerated test and the test acceleration are:

    \[
    \lambda_A = A_{\text{Test}} \cdot \lambda_0 = \sum_{i=1}^{S} \left( A_i \cdot \lambda_i \right)
    \]

    \[
    A_{\text{Test}} = \sum_{i=1}^{S} \left( A_i \cdot \left[ \frac{1}{S} \cdot \frac{\lambda_0 \cdot t_i}{\lambda_0} \right] \right)
    \]

  – Acceleration factor for individual stresses are determined using standard single stress accelerations. Thermal cycling and dwell are combined in test
Life Test Articles

- Government Provided Test Assets
  - Four Forebodies
  - Four Control Section Assemblies (CSA)
  - Remaining missile components have scheduled replacement during recertification – Limited Life Components (LLCs)
- Periodic performance testing and inspection throughout accelerated life test
- Perform Root Cause analysis for incurred failures
- Analyze test failure data to determine:
  - Failure mode probability/frequency and severity
  - Correlation between field data analysis and the life test results
  - Recommend mitigation measures for life extension
Accelerated Storage Life Test Flow

- Overall process for ASLT activities, which results in a test report
ASLT results - Forebody

- Testing executed in four Test Quarters (TQ)
  - Each TQ represented 5.5 years
  - Functional test before and after each TQ
  - TQ4 is 0.8 years longer due to restart after test chamber fan failure

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<th>Initial Age</th>
<th>TQ1</th>
<th>TQ2</th>
<th>TQ3</th>
<th>TQ4</th>
<th>Total</th>
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<td>8/29</td>
<td>10/3</td>
<td>12/16</td>
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<tr>
<td>Age (yrs)</td>
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<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>6.3*</td>
<td>43-46</td>
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</table>
ASLT results - CSA

- ASLT plan accelerates CSA ages by 22 years to 45 years in four TQs
  - Ten component and/or performance failures reported in three of the four test quarters (2nd quarter failure free)
  - Conducted failure mode analysis and mission criticality and life assessments
- Identified components as high risk to support 45 years

<table>
<thead>
<tr>
<th>Start Dates (2012)</th>
<th>Initial Age</th>
<th>TQ1</th>
<th>TQ2</th>
<th>TQ3</th>
<th>TQ4</th>
<th>Total</th>
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<tbody>
<tr>
<td>Age (yrs)</td>
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<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>45-47</td>
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</table>
Accelerated Storage Life Test Trend Data

• Trend plots developed for multiple test parameters reported in the Parametric Trend Analysis annual report
  – Quarterly ASLT Forebody data mapped to accelerated time

• Sample Forebody parameter indicates the acceleration testing had an effect on the parametric values

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CSA Trend Data

- Each of the CSA parameters stayed within specification limits over the 45 year data set.
- Sample parameter where Gain increases through test quarters showing influence of ALT testing however data remains under the upper limit at the end of 45 equivalent years.
MLE Summary

• ASLT test results were combined with Component Life Analysis
  – Objective: Determine presence of wear out mechanisms and degradation during the storage periods which may result in operational missile failures
  – Compiled storage life from missile inventory, material properties, and failures during ASLT to develop component risk assessments
  – Subsystem risk assessment was evaluated based upon roll-up of components to identify additional items to add/evaluate to the LLC list
• Recommended and Gov’t approved missile recertification beyond 30 years for 45 year life
  – Cost savings compared to buying new missiles
References

- IEC 62506, “Methods for products accelerated testing”
- Additional references supplied upon request
Speaker’s Bibliography

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