Health Management and Service Life for Air Force Missiles

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This briefing was about health management and service life for Air Force missiles.
Health Management and Service Life for Air Force Missiles

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Agenda

• Introduction
• Motivation
• Background / Previous Successes
• Current Work
• Tech Needs
• Summary and Conclusions
Introduction

• Solid motors are:
  • Simple: few moving parts, provide rapid response
  • Storable: no costly cryogenic or pressure systems required
  • Reliable: ready when needed, even after extended deployment

• However, solid rocket motors are:
  • Mechanically and chemically complex
  • Designed with small margins
  • Dynamic, changing with age and environmental exposure
  • Often required to function long beyond the design life
  • Often subjected to unexpected environments
  • Generally not capable of maintenance/repair
Motivation

Structural-Ballistic Interaction: Titan IV Solid Rocket Motor failure

Soft propellant deflects into flow, causes unexpected overpressure

Cost: Test stand damaged, Titan SRM destroyed, ~14 month program delay

Aging Failure: AIM-7 Sparrow explodes on launch from F-15

Chemical reaction of insulation curative degrades bondline to zero strength
Resulting structural-ballistic interaction causes missile to explode off wing

Cost: F-15 damaged, failure investigation
• In 1994, industry and government addressed the issue of service life prediction of rocket motors
• Consensus of the community was that the best predictions could be trusted to at most five years
• Only way to accurately improve predictions was to move to a mechanistic (first-principles) methodology
• Doubling the “look-ahead” window gives sufficient time to replace system without dramatically impacting readiness

Accurate method of predicting motor life prevents unnecessary replacement of good motors based on conservative service life predictions
AFRL Missile System A&S

Motor initial state and inspection data

Data Acquisition

Analysis

Command & Control

Data Processing and Storage

Sensors

Properties
Configuration
Environment
etc. - Capability

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Time

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Analysis Programs Overview

NDE Data Processing Program (1997)

CT Flaw Detection

Automated Flaw Evaluation

Critical Defect Assessment Program (1998)

Automated 2D Flaw Meshing

Automated Fracture Propagation

3D Structural/Ballistic Modeling

SRM Service Life Estimate

Critical Defects Analysis

Modulus (relative) vs Distance (mm)

Service Life Prediction Technology Program (1997)

Chemical/Mechanical Property Assessment and Prediction

Polymer Mechanics

Particle Packing

Nonlinear Viscoelastic Constitutive Modeling

AMPT Task Order 4 (2006)

Dewetting, and multi-scale crack coalescence

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Automated Multidisciplinary Solution Framework

- Detects and evaluates flaws in real motors
- Predicts future chemical-mechanical state
- Predicts motor performance and environment
- Predicts char, erosion, and thermal margins of safety
- Predicts structural integrity and margins of safety

Analysis software developed transitioned to industry — used on operational and development programs
Sensor Development

Instrumented, non-destructive life determination is the next step

Questions that must be answered:

• Effects of sensor on system safety and reliability
• Sensor optimization and placement
• Data acquisition, storage, transfer, and security
• Determination of minimal set of valuable data
Analysis of sensor location, sensitivity requirements – Dr. Timothy Miller

Sensor Number and Location Optimization

Propellant experiences tensile radial stresses as it tries to pull away from the case.

When a crack develops, the stresses are released near the crack.

Relationship between crack size, number of sensors, sensor sensitivity
Smart Weather Seal

- Small, light, and inexpensive with no batteries
- Electronics/sensors attached to weather seal
- Includes break-away connections for firing
- Initially includes temperature and humidity sensors, and accelerometer
Lifecycle Data Management

Analysis → Command & Control

Data Processing and Storage

End use or disposal

Operational life

NDE and depot operations

Transfer to the government and storage

Transportation

Manufacture

Designs

Parts & Supplies

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Sensor Tech Needs

• **Modulus sensors:**
  • Method to determine various mechanical moduli throughout the asset

• **Chemical sensors:**
  • A method to measure the chemical changes in the PLI are driven by chemical diffusion-reaction processes
  • Field measurements would be of substantial benefit

• **Non-contact sensors**
  • Compact, transportable systems to replace depot inspections with CT, UT, X-ray, or other techniques
  • External sensors to replace embedded sensors
Analysis Tech Needs

- Flaw behavior during operation
  - Physics based models
  - Addition of new physics to modeling framework
- Enhanced coupling of modeling technologies
- Validation Data
  - Motor firing data
  - Physical property measurement
Summary and Conclusions

- Solid rocket motors are a unique and challenging environment for health monitoring.
- Current AFRL aging and surveillance effort addresses analysis, sensors, and data management.
- Future opportunities exist in the areas of:
  - Advanced analysis capabilities
  - Validation data
  - Sensors
  - Technology integration

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Questions?
Data Manager System

- Security
- Policy control
- Modular software
- XML schema
- Journal-based feedback
- Tools to manage/retrieve
- Standards-based communication
- Structured, integrated data storage

Manage All Data from Birth to End of Life

Missile Logistics & Management

Analysis and Prediction

Data Warehouse/Management

Designer/Analyst

Suppliers

Parts & Materials

Fabricator

Storage Facility

Inspection Facility

Air Force Base

Silos

Storage Bunkers

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Non-Destructive Flaw Assessment

- ANDES/2 code analyzes X-ray CT scan, detects voids, inclusions, and debonds
- Flaw data automatically incorporated into existing baseline model and analyzed

ANDES/2 in daily use for motor inspections
Sensor Application/Modeling

- Demonstrate embedded sensors in near-production environment
- Bond strength test results
  - Multiple sensors embedded in SRM liner, tested in tension and shear
    - No failures through sensors
    - No change in bond system strength
    - No damage to sensors from storage/handling
- Demonstration of bore crack detection with bondline sensors
- 10” analog motors fired successfully, stored for long-term aging study
### Aging and Surveillance Relationship to Other Work

<table>
<thead>
<tr>
<th>1994 SOTA</th>
<th>A&amp;S Programs Advancements</th>
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<tbody>
<tr>
<td>• Linear elastic constitutive model</td>
<td>• NLVE constitutive model</td>
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<tr>
<td>• Uncoupled or manually coupled analyses</td>
<td>• Mechanistic model for filled polymer constitutive behavior</td>
</tr>
<tr>
<td>• 0D or 1D Fluid Mechanics</td>
<td>• Coupled structures-ballistics-burnback analysis, fully 3D</td>
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<tr>
<td>• Automated Pass/Fail of CT scanned motors</td>
<td>• Automated coupled solution, scriptable</td>
</tr>
<tr>
<td>• Flaw resolution of 40 mils</td>
<td>• Automated analysis speed increased 50x</td>
</tr>
<tr>
<td>• Flaws, voids, fractures input and propagated by hand</td>
<td>• Flaw resolution increased</td>
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<tr>
<td>• Material aging assumed to follow Layton (logarithmic) aging law</td>
<td>• Future chemical state prediction from actual chemical processes</td>
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<tr>
<td>• Maximum service life look ahead 5-years</td>
<td>• Material property changes from chemical/mechanical link</td>
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<tr>
<td>• Future chemical state prediction from actual chemical processes</td>
<td>• Service life look-ahead 10 years with 90% reliability/90% confidence</td>
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Integrated Motor Life Management (IMLM)

• Design a system to accurately predict the ability of a specific solid rocket motor (SRM) to perform its intended mission

• Task 1: Baseline the System
  • Identify high TRL sensors, analysis software, and other associated components necessary to deploy a prototype

• Task 2: Integration and Assembly of Prototype/Breadboard System
  • Assemble prototype/breadboard system using the proposed technologies
Integrated Motor Life Management (IMLM)

• Task 3: Demonstrate Integrated Prototype on Motor Analogs
  • Demonstrate integrated prototype in relevant environments at a laboratory scale – confirm system capabilities

• Task 4: Demonstrate Integrated Prototype System in Relevant Environments
  • Subscale motors will demonstrate all aspects of the IMLM system
  • A representative scale motor will be analyzed and monitored while manufactured, aged, transported, transferred to the government, and tested
  • True prediction of performance will be conducted

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• Empiricism cannot always predict future state
• Mechanistic method enables enhanced predictions
  • Mechanistic will not be worse than empirical approach
Empiricism cannot always predict future state

Mechanistic method enables enhanced predictions
  - Mechanistic will not be worse than empirical approach
# IMLM Program Schedule

## Task 1: System Baseline
- **FY10**: Kick off

## Task 2: Integration & Assembly of System
- **FY12**

## Task 3: Demonstrate Prototype System on Motors Analog
- **FY13**

## Task 4: Demonstrate system in Relevant Environment
- **FY14**

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