Seeded Failure Testing and Analysis of an Electro-Mechanical Actuator

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Parker Aerospace
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**F35 Integrated Prognostics and Health Management**

### Air Vehicle On-Board Health Assessment

- **PHM Area Managers**
  - ICAWS Manager
    - Hosted in VMC
- **PHM Managers**
  - Propulsion
  - VS
  - FCS/Utility Subsystems
  - Structures
- **Mission Systems**
  - MS Subsys

### Health Management, Reporting & Recording

- **AVPHM**
  - Hosted in ICP
- **NVM**
- **Crash Recorder**
- **PVI**
- **Mission Critical**
- **PHM Data**
- **AMD/PMD**
- **In-Flight & Maintenance Data Link**
- **PMA**
- **Maintenance Interface Panel**

### Autonomic Logistics & Off-Board PHM

- **Results In**:
  - Decision Support
  - Troubleshooting and Repair
  - Condition-Based Maintenance
  - Efficient Logistics

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**Methods Used**:
- Sensor Fusion
- Model-Based Reasoning
- Tailored Algorithms
- Systems Specific Logic / Rules
- Feature Extraction

**Provides**:
- AV-Level Info Management
- Intelligent FI
- Prognostics/Trends
- Auto. Logistics Enabling/Interface

**AVPHM**

**ALIS**
- Automated Pilot / Maint. Debrief
- Off-Board Prognostics
- Intelligent Help Environment
- Store / Distribute PHM Information

**Database**
Technical Program

Objectives

• Develop Competency in Seeded Failure Testing
• Develop Competency in Failure Prognosis

Technical Approach

• Utilize Multiple Actuators – Statistical Significance
  ✓ Parker ½ HP EMA Selected
• Dynamic Controls, Inc. (DCI) Selected to do Testing
• Examine FMECA, Select Components for Failure Testing
• Identify Reliable Failure Pre-cursors
  ✓ Minimal Sensors
Electro-Mechanical Actuator Characteristics

<table>
<thead>
<tr>
<th>Description</th>
<th>Qty</th>
<th>Failure Rate by Assembly (% of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballscrew Assembly</td>
<td>1</td>
<td>16.20%</td>
</tr>
<tr>
<td>Gearbox Assembly</td>
<td>1</td>
<td>8.30%</td>
</tr>
<tr>
<td>Motor Assembly</td>
<td>1</td>
<td>39.70%</td>
</tr>
<tr>
<td>Housing Assembly</td>
<td>1</td>
<td>1.80%</td>
</tr>
<tr>
<td>Position Potentiometer A</td>
<td>1</td>
<td>34.00%</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>

- Actuator Pin-to-Pin Length: 12,000 inches (fully extended)
- Actuator Stroke: ± 0.875 inches
- Actuator Performance:
  - 2.0 in/sec @ 1620 lbs. Load
  - 3.7 in/sec @ 214 lbs. Load
- Bandwidth: 6 Hz @ -90 Deg
- Stall Load: 2400 lbs. @ 65 A Current limit

Pinion to Cluster Gear: 3 to 1
Cluster Gear to Output Gear: 3.125 to 1
Ball Screw to Ram (rev/in): 5 to 1

Bandwidth: 6 Hz @ -90 Deg
## Selected Test Components

<table>
<thead>
<tr>
<th>Description</th>
<th>Failure Rate (X10-6/Hr)</th>
<th>Temp Factor</th>
<th>Applic. Factor</th>
<th>Qty</th>
<th>Total Failure Rate Contribution (x10-6/HR)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ball Screw Assembly</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball Screw</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Thrust Bearing</td>
<td>0.1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Gearbox Assembly</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cluster Gear Bearing</td>
<td>0.1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0.4</td>
</tr>
<tr>
<td>Output Bearing</td>
<td>0.1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Motor Assembly</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor Bearing</td>
<td>1.15</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2.3</td>
</tr>
</tbody>
</table>

*Components That Will be Tested to Failure*
EMA Components Tested

- Motor
- Pinion
- Ballscrew Assembly
- Output Rod
- Motor
- Output Gear
- Cluster Gear
- Gear Pin
- Bearings
- Thrust Bearings (both ends)
- Thrust Bearing
- Motor Bearing
- Motor Bearing
- Motor Bearing
- Motor Bearing
- Ball Screw
- Cluster Bearing
- Output Bearing
- Output Bearing
Test Facility

- Test Rigs Built to Test Six Actuators Simultaneously

Testing at Dynamic Controls, Inc. in Dayton, OH
Failure Definition

- Based on ATP Performance Requirements
- Failure to Meet 90% of a Performance Requirement
  Deemed an Actuator Failure
- Performance Values Used:
  - Minimum actuator rate at specified load
  - Unloaded frequency response
  - Backlash more than specified end-of-life value
- Actuators run until either short-stroke (stalled into spring load) or a motor over-temperature occurred.
**Failure Seeding**

- **Objective** - Wearout Components to Failure Criteria in Approximately 24 Hours
- **Diamond Lapping Compound Mixed With Lubricant to Accelerate Wear**
  - √ Evaluated Various Grit Sizes and Ratios of Lubricant to Diamond Lapping Compound
  - √ Ball Screw Thrust Bearing Used in Evaluations

<table>
<thead>
<tr>
<th>RunID No. (Actuator S/N)</th>
<th>Failure Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>RunID 9/Act1 (54)</td>
<td>19.3</td>
</tr>
<tr>
<td>RunID 9/Act2 (57)</td>
<td>20.9</td>
</tr>
<tr>
<td>RunID 9/Act3 (56)</td>
<td>27.1</td>
</tr>
<tr>
<td>RunID 10/Act1 (54)</td>
<td>15</td>
</tr>
<tr>
<td>RunID 10/Act2 (57)</td>
<td>14.7</td>
</tr>
<tr>
<td>RunID 10/Act3 (56)</td>
<td>23.2</td>
</tr>
</tbody>
</table>

Average Failure time: 19.4
Standard Deviation: 5.0

**Development Tests**
Failure Pre-Cursors

Consider the EMA From a Control Volume Point of View

\[ e = \frac{\text{Power Out}}{\text{Power In}} \]
Sensors

- **Available**
  - √ Ram Position
  - √ Load
  - √ Motor Current Draw
  - √ Motor Position

- **Added**
  - √ Accelerometer - 2 Axis
  - √ Motor Temperature
Test Duty Cycles

Data Snapshots

- Performance Data every 30 minutes
  - Hysteresis
  - Loaded Actuator Rate
  - Frequency Response
  - Accelerometer Data
- Status Data Every 10 Minutes
  - Current
  - Temperature
  - BIT Tests

Red Indicates Loads in Negative Direction
Data Analysis – Actuator Efficiency (Seeded Thrust Bearing)

Raw Data

Filtered Data
( Filtering Allows Failure Prediction and Isolation)
Data Analysis – Frequency Response/Coherence
(Seeded Thrust Bearing)

Coherence

Frequency Response

Coherence Frequencies vs. Time

3dB and 6dB Frequencies vs Time
Data Analysis – PSD Plots
(Seeded Thrust Bearing)

- Accelerometer Data Did Not Provide Useful Information
  - Ram Velocity is Constantly Changing → Gear Frequencies are Constantly Changing
  - Need Accurate Position Information For Velocity Synchronous Averaging

![PSD Plot Image]
Summary Comments

- Lubricant Contamination in the Bearings Provided Reasonable Control of the Time to Failure

- The Thrust Bearings were the Most Detectable Component Failure Since They Directly Reacted the Actuator Axial Loads
  - Output Gear Bearings were Also Detectable
  - Motor Bearing and Cluster Gear Bearing Failures Were Difficult to Detect From an Efficiency Approach – Other Methods Required.

- Defining Failure Criteria Requires Some Thought

- Need to Consider Wear of non-seeded Parts During Testing