CKU-5C/A Rocket Motor Mechanistic Service Life Evaluation

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Overview

- Background
- Mechanistic Approach
- Disassembly and Dissection
- 0-Time Testing
- Propellant Aging
- Results
- Conclusions

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Background

- A service life evaluation was performed for a foreign customer on the CKU-5C/A ejection seat rocket motor
- A two phase, mechanistic approach was utilized
  - Phase I involves determining potential failure modes and characterizing the motor
    - One CKU-5C/A was tested for Phase I of this study
      - About 63 months old at the time of testing
  - Phase II involves a study of motor to motor variation and how the propellant ages
    - Two CKU-5C/A motors were tested for Phase II of this effort
      - One motor was dissected and portions of it tested at about 5.5 years of age
        - Other portions were aged up to 12 months at varying temperatures and then tested
      - A 3.9-year-old motor was static tested at high temperature

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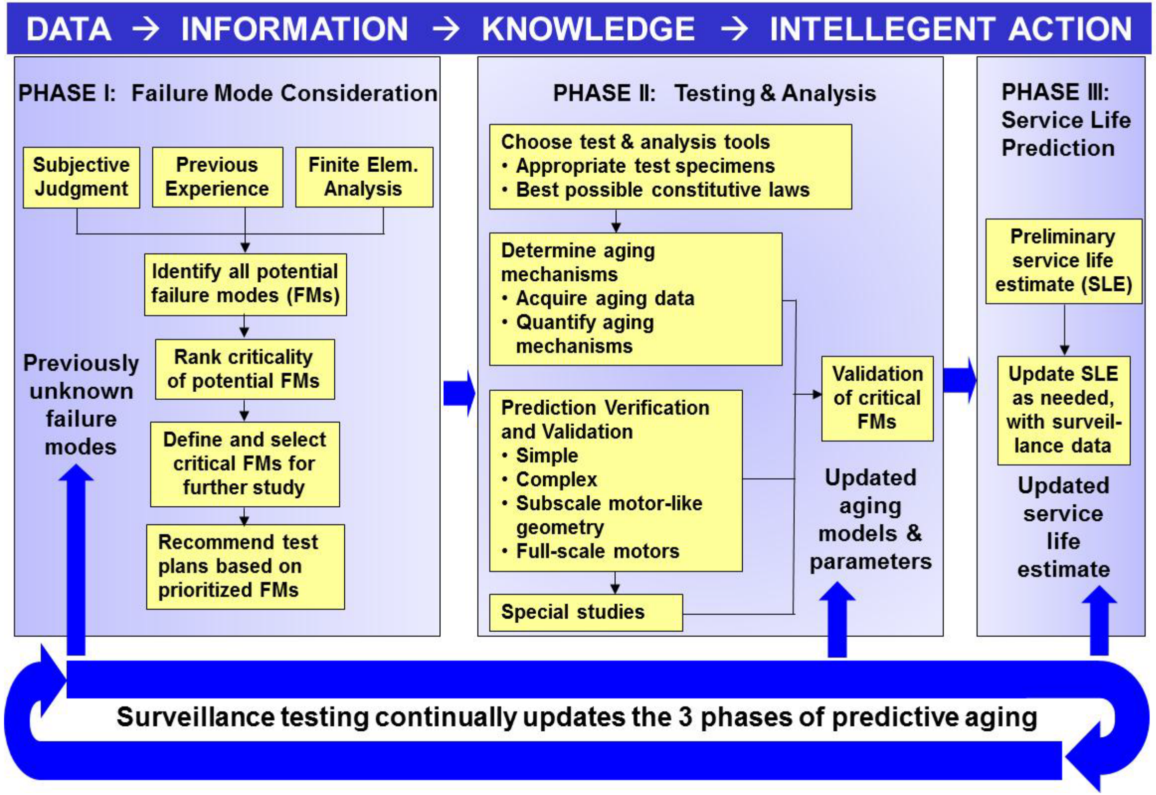
Mechanistic Approach

- This study is part of the iterative approach to mechanistic aging



Mechanistic aging doesn't just track aging trends but focuses on what causes the properties to change

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Aging Sensitivity Ranking

- Components are ranked based on aging sensitivity and criticality factors
  - Assumed to be manufactured to specifications
  - Manufacturing defects/deviations are not considered
- Higher failure potential factors (lower FPF) are given higher priority for evaluation

Age Sensitivity Factor (ASF)	Criticality Factor (CF)	Failure Potential Factor (FPF = ASF x CF)
1) Definite likelihood of material degradation.	1) Failure mode is likely to occur, with safety factor less than 1.5.	1, 2 Critical
2) Likelihood of material degradation uncertain.	2) Failure mode occurrence is uncertain, with safety factor between 1.5 and 2.0	3, 4 Moderately critical
3) No immediate likelihood of material degradation.	3) Failure mode is unlikely, with safety factor > 2.0	6, 9 Not critical

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Motor Failure Modes

Material/ Component	Component Failure Mode	ASF	CF	FPF	System Effects
II. Propellant - Ballistics					
	1) Ballistic performance specification violation	1	2	2	Catastrophic

Material/ Component	Component Failure Mode	ASF	CF	FPF	System Effects
III. Bondlines					
	1) Propellant-liner-case bond failure:				
	a) High temperature storage	1	3	3	Catastrophic
	b) Low temperature storage	1	2	2	Catastrophic
	c) High temperature operation	1	3	3	Catastrophic
	d) Low temperature operation	1	3	3	Catastrophic
	e) Shock and vibration	1	3	3	Catastrophic
IV. Case (4130 Steel)					
	3) Case rupture due to internal heating, or burn-through	1	2	2	Catastrophic

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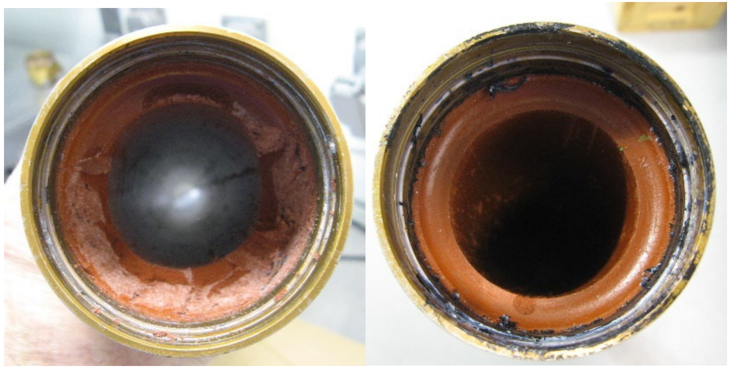
Disassembly

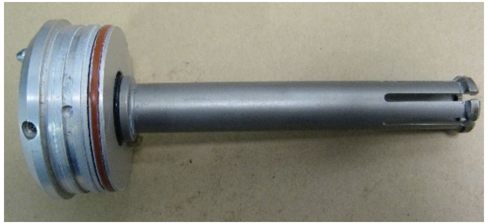
- Motors were disassembled to prepare for dissection

Impulse Tube

Nozzle



Ends of Main Motor



Head

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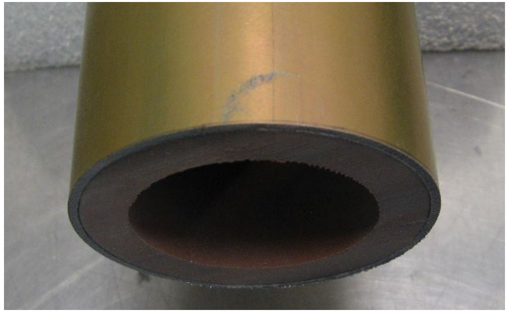
Dissection

- Motors were dissected at Redstone Arsenal via grit blasting for Phase I of this effort
  - Significant variability in the dissected samples required rework so that the samples were acceptable for testing
- A diamond wire saw (DWS) was used to dissect motors for Phase II at ATK

Grit Blasted Bondline Samples

Grit Blasted Coin

DWS Cut Bondline Samples



DWS Cut Coin

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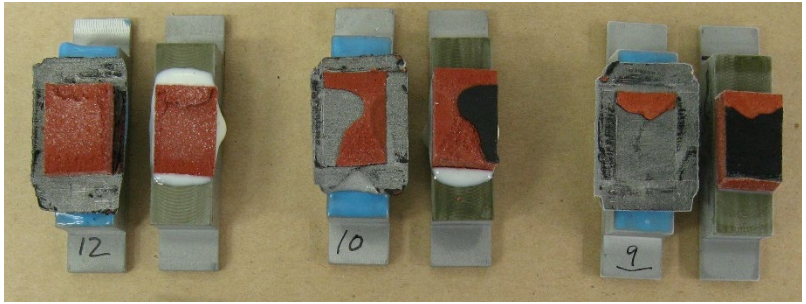
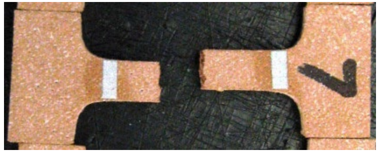
0-Time Testing

- Baseline testing was performed to obtain propellant properties prior to aging
- Testing included
  - Bondline Shear
  - Bondine Tensile
  - Uniaxial Tensile (Dog Bone)
  - Chemical Profile
  - Mechanical Profile
  - Relaxation Modulus (Prism)



Tested Bondline Shear Specimens

Tested Prism



Tested Dog Bone

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Propellant Aging

- Motor “coins” were aged at various times and temperatures
- One motor was dissected and individual “coins” aged
- The same test matrix was utilized at each aging interval

Age Time (months)	Age Temperatures		
	75°F (24°C)	120°F (49°C)	150°F (66°C)
0	X	-	-
2	-	-	X
3	-	X	-
6	-	-	X
12	X	X	-

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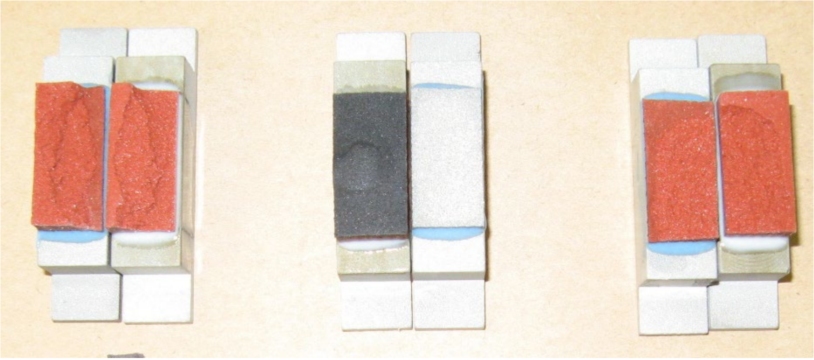
Aged Propellant Testing

- Baseline testing was performed to obtain propellant properties prior to aging
- Testing included
  - Bondline Shear
  - Bondine Tensile
  - Uniaxial Tensile
  - Chemical Profile
  - Relaxation Modulus
  - Shore A Hardness



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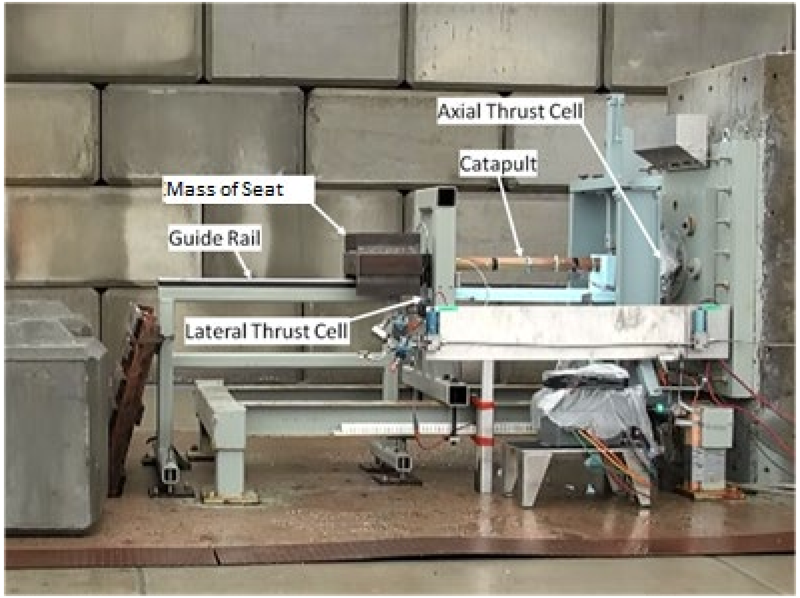
Static Test

- Static testing was performed on a motor in which the head had been ported for the addition of pressure transducers
- Testing was recorded with a normal speed and high-speed video camera



Static Test Layout

Ported Head

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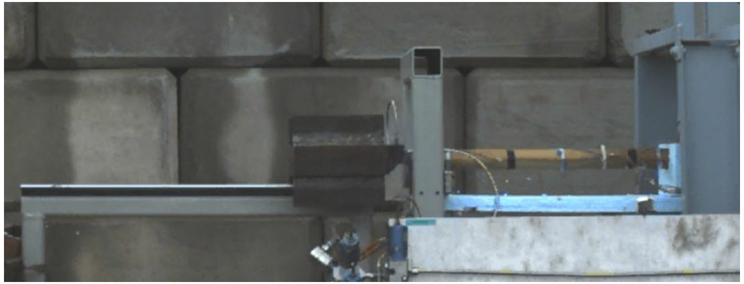
Static Test



Start of Catapult Phase

Start of Rocket Motor Phase

Near End of Catapult Phase

Near End of Rocket Motor Phase

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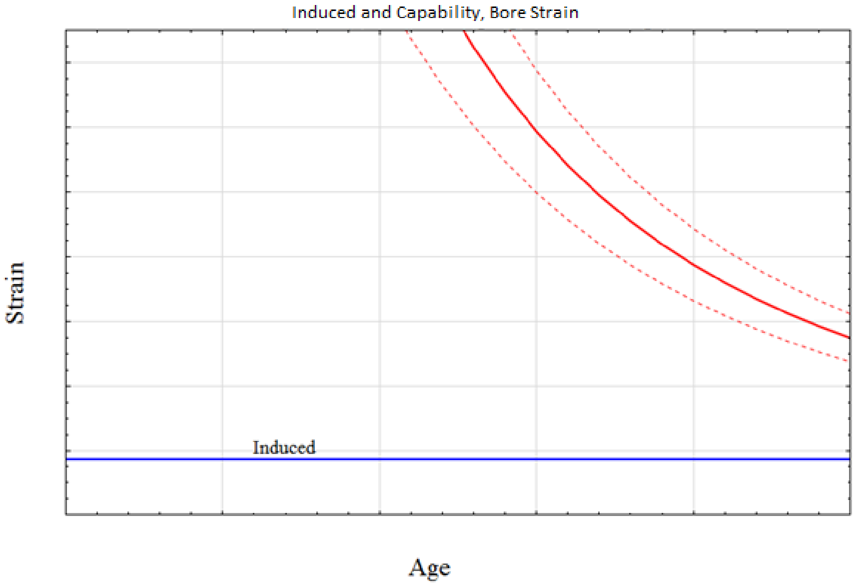
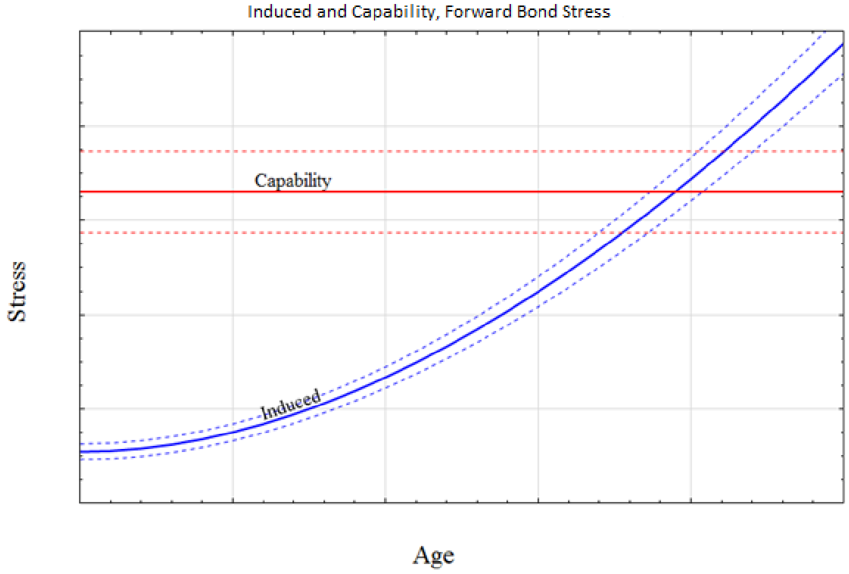
Results



Induced and Capability, Forward Fillet Strain



Induced and Capability, Bore Stress

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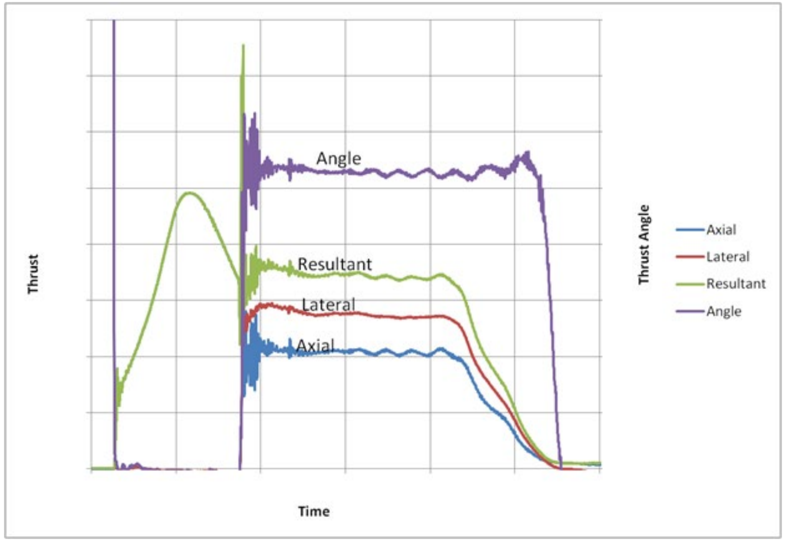
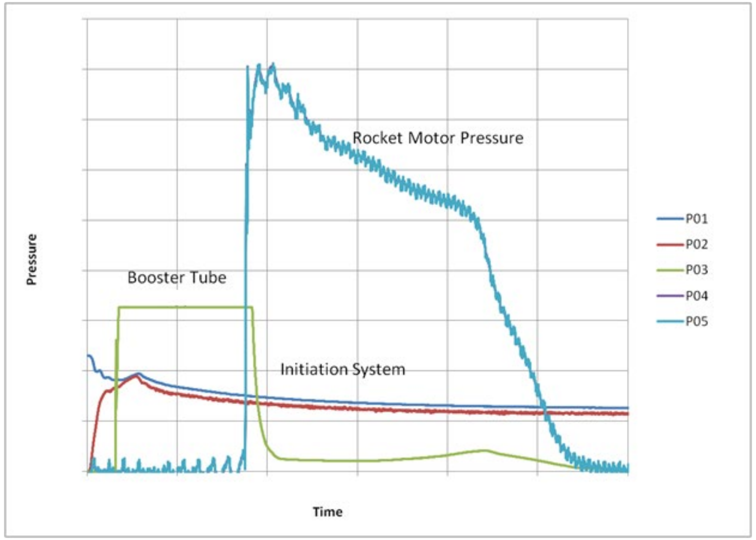
Static Test Results



Thrust Plot



Pressure Plot

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Conclusions

- Probability of failure of motors older than the design service life are higher when used near the lower specification temperature
  - Due to the service environment of these articles, this is highly unlikely
- Service at higher temperature reduces the service life of the rocket
  - The probability of failure may be up to five times higher twice when the rocket is twice as old as its design life depending on environmental conditions the rocket was subjected to
    - Higher temperatures shorten the service life
- Confidence level of these predictions are low since data is from a small number of dissected motors

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Recommendations

- Perform additional dissections and static firings on motors when they approach twice the design service life
  - This will help validate the current predictions and may further extend the service life
  - A cold static test would be an extreme condition that would further improve confidence in these predictions
- Track the environmental conditions under which the articles are stored or in service to verify assumptions made for this analysis

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