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Helicopter Engine Compatibility Background

- **Problem description:**
  - AH-1F downed with fatalities in 1988 while firing MK 66 Rocket Motors
  - Army investigation concluded that the accident was caused by engine ingestion of high-temperature, oxygen-depleted rocket exhaust gasses
    - AH-1 physical mod implemented (air scoop)
AH-64 testing identifies rocket exhaust ingestion into engines still a problem

- Causes engine torque splits and torque fluctuations (surges)
- Physical mod to aircraft considered not practical
- Firing restrictions in effect
Helicopter Engine Compatibility Background

- High temperature oxygen depleted rocket exhaust caused by secondary combustion
- Secondary combustion (afterburning) occurs when CO and H₂ in the exhaust react with oxygen in atmosphere

Current MK 66 exhaust components

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<th>Combustion Component</th>
<th>Exit Composition (mole fraction)</th>
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<td>H₂</td>
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<td>N₂</td>
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MK 66 Rocket Motor Background

MK 66 MOD 4 ROCKET MOTOR
Helicopter Engine Compatibility Approach

- Secondary combustion can be suppressed by introducing more potassium sulfate ($\text{K}_2\text{SO}_4$) into motor exhaust
  - Mod 0-4 Salt Rod addresses rocket exhaust ingestion issue in fixed wing aircraft
  - Helicopter ingestion situation is the same
    - Ingestion timeline is different
    - Existing salt rod consumed in 6 feet of motion
    - Helicopters need salt rod effect through rotor downwash
    - Army Aviation Engineering specifies 30 feet as necessary
• There is a linear relationship between salt volume and duration of afterburning suppression

• Amount and shape of salt rod modified to increase effectiveness for 30 feet

• Enlarged salt rod contains ~ 3x more $\text{K}_2\text{SO}_4$

**MOD 4**

- 0.5 INCH DIA X 6 INCH LONG SALT ROD
- 0.33 INCH DIA X 4 INCH LONG SALT ROD
- 0.5 INCH DIA X 15.3 INCH LONG SALT ROD
Exhaust Chemical Analysis

- **K₂SO₄ reactions**
  - **Afterburning reaction:**
    \[
    2\text{CO} + 3\text{H}_2 + 2\text{OH} + 2\text{O}_2 \Rightarrow 2\text{CO}_2 + 4\text{H}_2\text{O}
    \]
    Atmospheric oxygen
  - **Reaction with K₂SO₄:**
    \[
    \text{K}_2\text{SO}_4 + 2\text{CO} + 3\text{H}_2 + 2\text{OH} + 2\text{O}_2 \Rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O} + \text{H}_2\text{S} + \text{KO} + \text{K} + 2\text{O}_2
    \]
  - **K₂SO₄ provides oxygen to the exhaust, which delays the overall reaction of the exhaust fuels (H₂ and CO) with the atmospheric oxygen (O₂)**
Static Fire Test
Static Fire Test Results

- Motor exhaust temperature found to be more than 20% lower than current MK 66 motors at 77 F and 150 F
Ground Launch Results

- Suppressed flight distance >30 ft average
Ground Launch Results

- Ground launch thermal data

MK 66 MOD 3 ROCKET MOTOR (150 F)  
HELICOPTER COMPATIBILITY ROCKET MOTOR (150 F)
Air launch test on an instrumented AH-64A with MK 66 motors w/ enlarged salt rod conducted in 1998

Test conditions
- 10 knot wind restrictions
- Altitude was 150 ft
- Air temperature was in upper 70s, 70-80% RH

Test pass/fail criteria:
- Torque split exceeds 15%,
- Main engine torque fluctuations of ±15%,
- Tail rotor torque fluctuations of ±500 ft-lbs
Air Launch Results

- All engine surge conditions eliminated except one
  - Hover: All surge conditions eliminated
  - 40 kts forward flight: All conditions but one eliminated

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<th>CONDITION</th>
<th>LEFT OUTBOARD</th>
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Air Launch Results (cont.)

- **Worst condition:** 40 kts forward flight, one or two rockets fired from left inboard launcher
- Enlarged salt rod causes ignition pressure spikes
  - Enlarged salt rod known to increase pressure, and therefore thrust during ~ 0.10 second of burn
  - Measured thrust values near MK 66 specification limit of 2100 lbf
Pressure Differential Test

- Thrust requirement derived from internal forward end measured pressures
- Aft end known to be weakest point on motor (lockwire joint)
- Efforts made to measure pressure at aft end
Pressure Differential Test

- Pressure differential test performed at Indian Head in June 2002
  - Previous analysis predicted a 350 - 500 psi drop at 150°F
  - Aft pressures measured ~400 psi lower than forward end during first 0.10 seconds at 150°F
• Thrust limit redefined based on aft end pressures
  – Recommended a new thrust limit of 2500 lbf for the first 0.10 seconds of burn
  • Maintains motor tube factor of safety of 1.5
  • Verified by analysis and historical data

![New Thrust Limit Graph]

Thrust Limit = 2500 lbf
Thrust Limit = 2100 lbf
Thrust Limit = 2350 lbf
Thrust Limit = 2900 lbf

0.1 s 0.5 s 0.7 s

MOD 4
Modified
Future Work

- Enlarged salt rod design will be incorporated into the MK 66 MOD 6
- Qualification of MOD 6 scheduled to begin in this spring
  - Qualification includes:
    - Environmental Tests
    - Ground Launch
    - Air Launch
- Due to enter production midway through FY04
Questions

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