MK 66 ROCKET MOTOR/HELICOPTER COMPATIBILITY PROGRAM

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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)**

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Helicopter Engine Compatibility Background

- **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**

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Helicopter Engine Compatibility Background

- **High temperature oxygen depleted rocket exhaust caused by secondary combustion**
- **Secondary combustion (afterburning) occurs when CO and H_2 in the exhaust react with oxygen in atmosphere**

Current MK 66 exhaust components

Combustion Component	Exit Composition (mole fraction)
CO_2	0.1898
CO	0.33007
H_2O	0.18146
H_2	0.17295
N_2	0.12218
Pb	0.00177
Cu	0.00177

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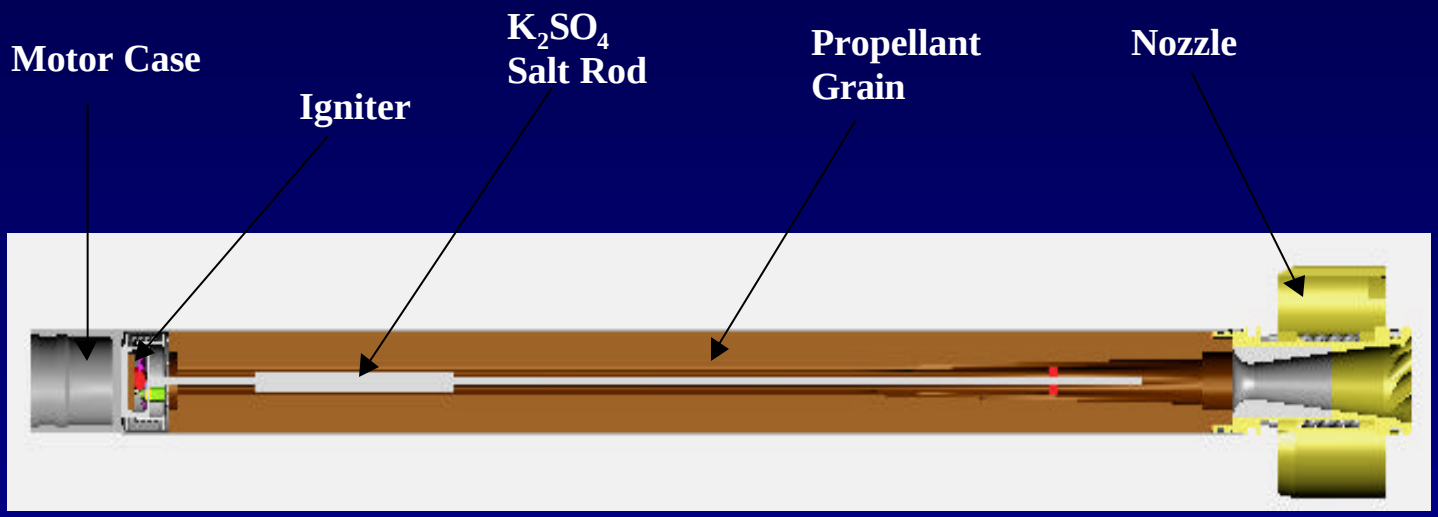
MK 66 Rocket Motor Background



MK 66 MOD 4 ROCKET MOTOR

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Helicopter Engine Compatibility Approach

- **Secondary combustion can be suppressed by introducing more potassium sulfate (K_2SO_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**

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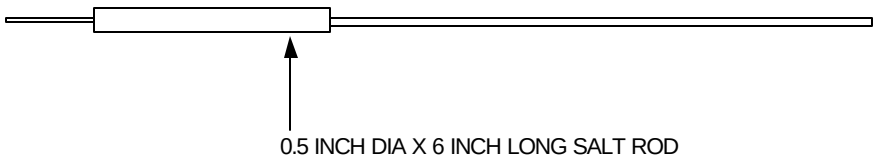
Salt Rod Modification

- 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 K_2SO_4

MOD 4



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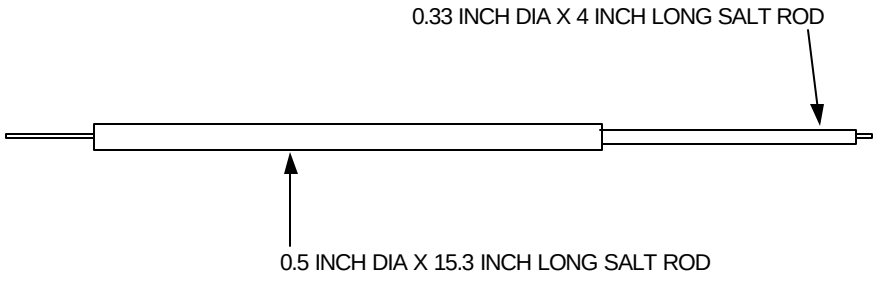

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Exhaust Chemical Analysis

- K_2SO_4 reactions
  - Afterburning reaction:

$$2CO + 3H_2 + 2OH + 2O_2 \Rightarrow 2CO_2 + 4H_2O$$

Atmospheric oxygen

  - Reaction with K_2SO_4:

$$K_2SO_4 + 2CO + 3H_2 + 2OH + 2O_2 \Rightarrow 2CO_2 + 3H_2O + H_2S + KO + K + 2O_2$$

  - K_2SO_4 provides oxygen to the exhaust, which delays the overall reaction of the exhaust fuels (H_2 and CO) with the atmospheric oxygen (O_2)

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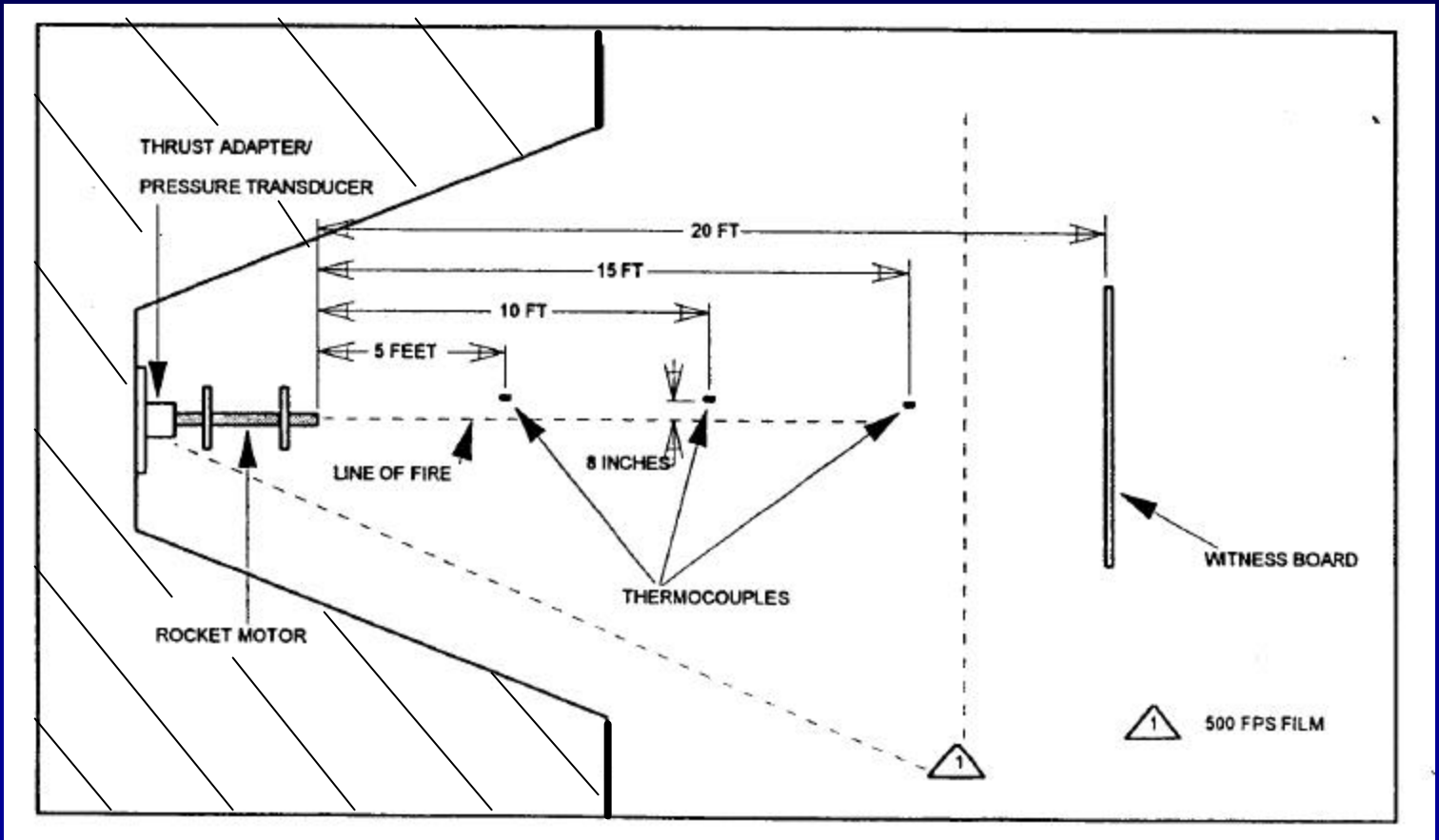
Static Fire Test



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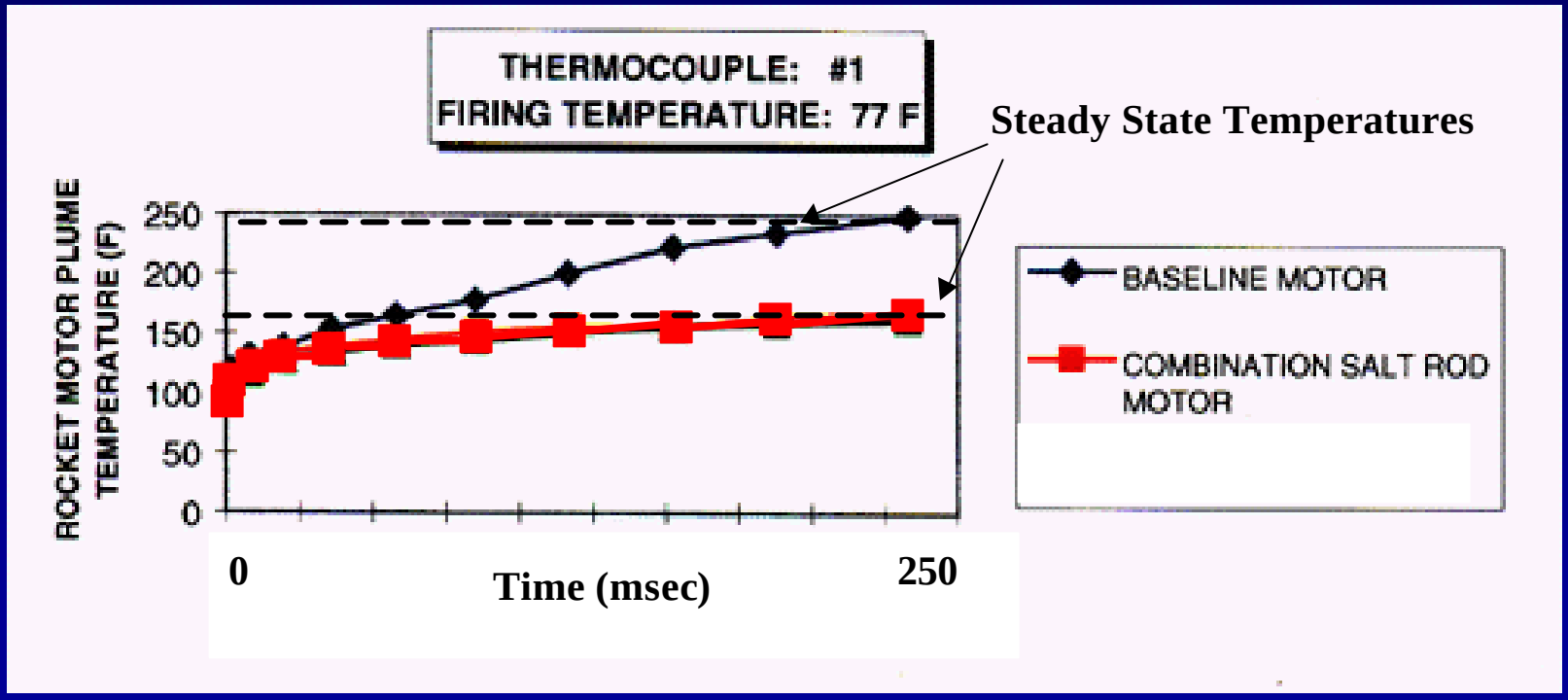
Static Fire Test Results

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



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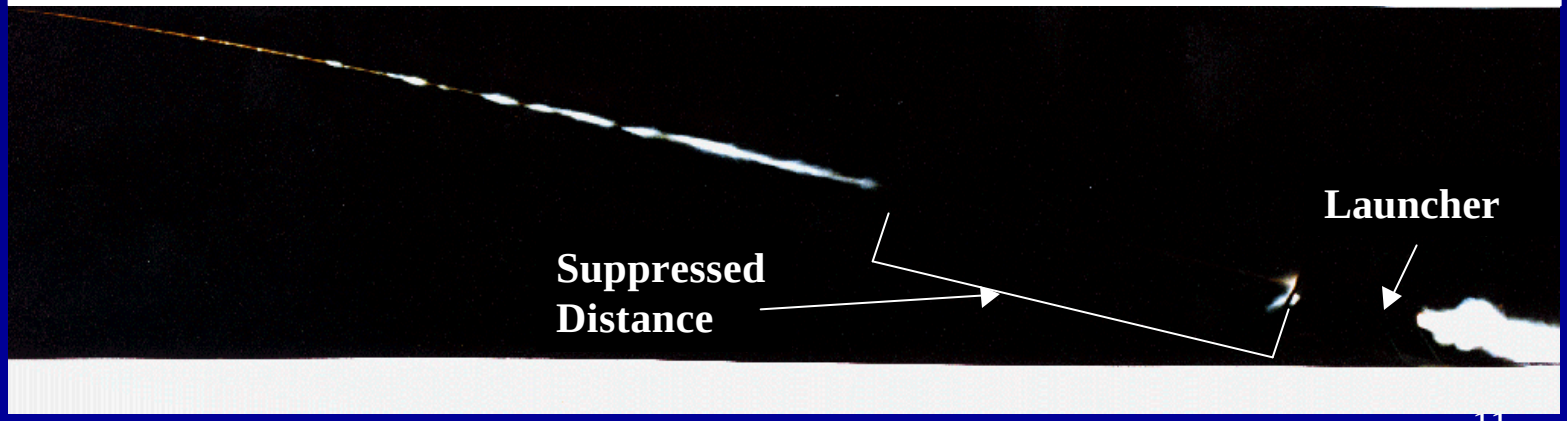
Ground Launch Results

- **Suppressed flight distance >30 ft average**

MK 66 MOD 3 ROCKET MOTOR (150 F)

HELICOPTER COMPATIBILITY ROCKET MOTOR (150 F)



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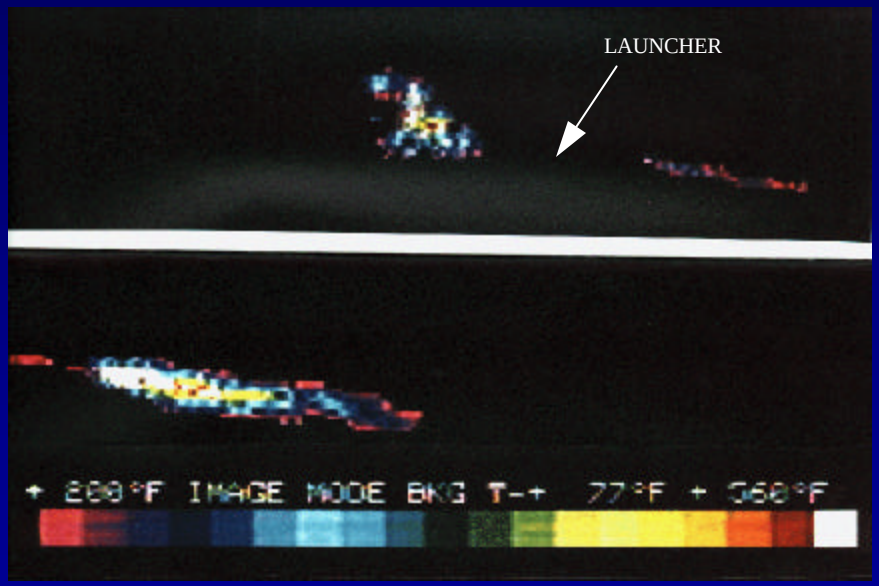
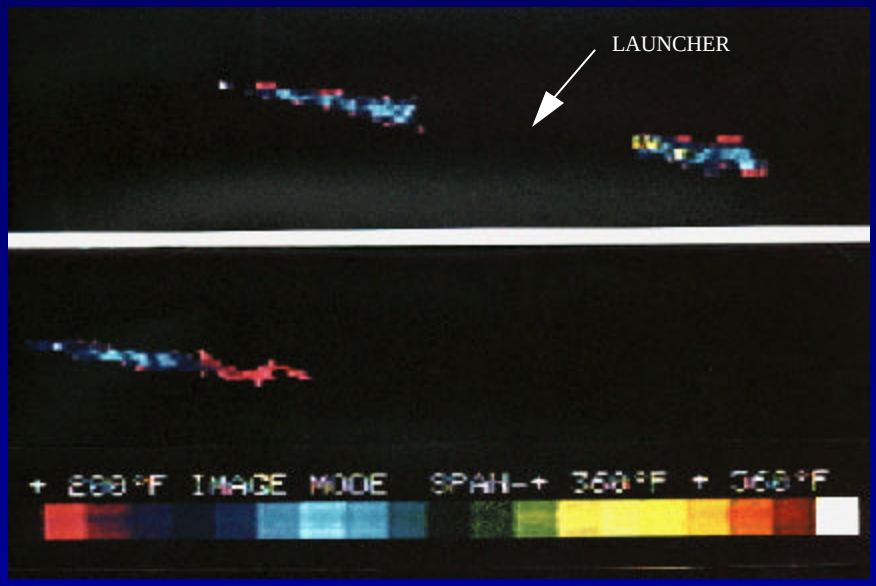
Ground Launch Results

- **Ground launch thermal data**

MK 66 MOD 3 ROCKET MOTOR (150 F)



HELICOPTER COMPATIBILITY ROCKET MOTOR (150 F)



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Air Launch Verification

- **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**

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Air Launch Results

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

CONDITION	LEFT OUTBOARD		LEFT INBOARD		RIGHT INBOARD		RIGHT OUTBOARD		MK 66 MOD 3 ROCKET MOTOR	HELICOPTER COMP ROCKET MOTOR
	ROCKET DENSITY	ROCKETS FIRED	ROCKET DENSITY	ROCKETS FIRED	ROCKET DENSITY	ROCKETS FIRED	ROCKET DENSITY	ROCKETS FIRED		
HOVER	10	2								
	8	8								
	12	12								
	19	19								
	19	19					19	19		
			14	2					1	TESTED TWICE
			12	4					1	TESTED TWICE
			8	8						
					19	2				
					17	2				
					15	2				
40 KTAS FORWARD	16	4								
	12	12								
	19	19								
			19	2/1					1	1, 1 (NOTE 1)
			17	2/1					1	1 (NOTE 2)
			15	2						
			2	2						
					19	2			1	TESTED TWICE
					17	2			1	TESTED TWICE
					15	2			1	TESTED TWICE
	12	4					12	4	1	TESTED TWICE
	8	8					8	8	5	

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Air Launch Results (cont.)

- **Worst condition: 40 kts forward flight, one or two rockets fired from left inboard launcher**

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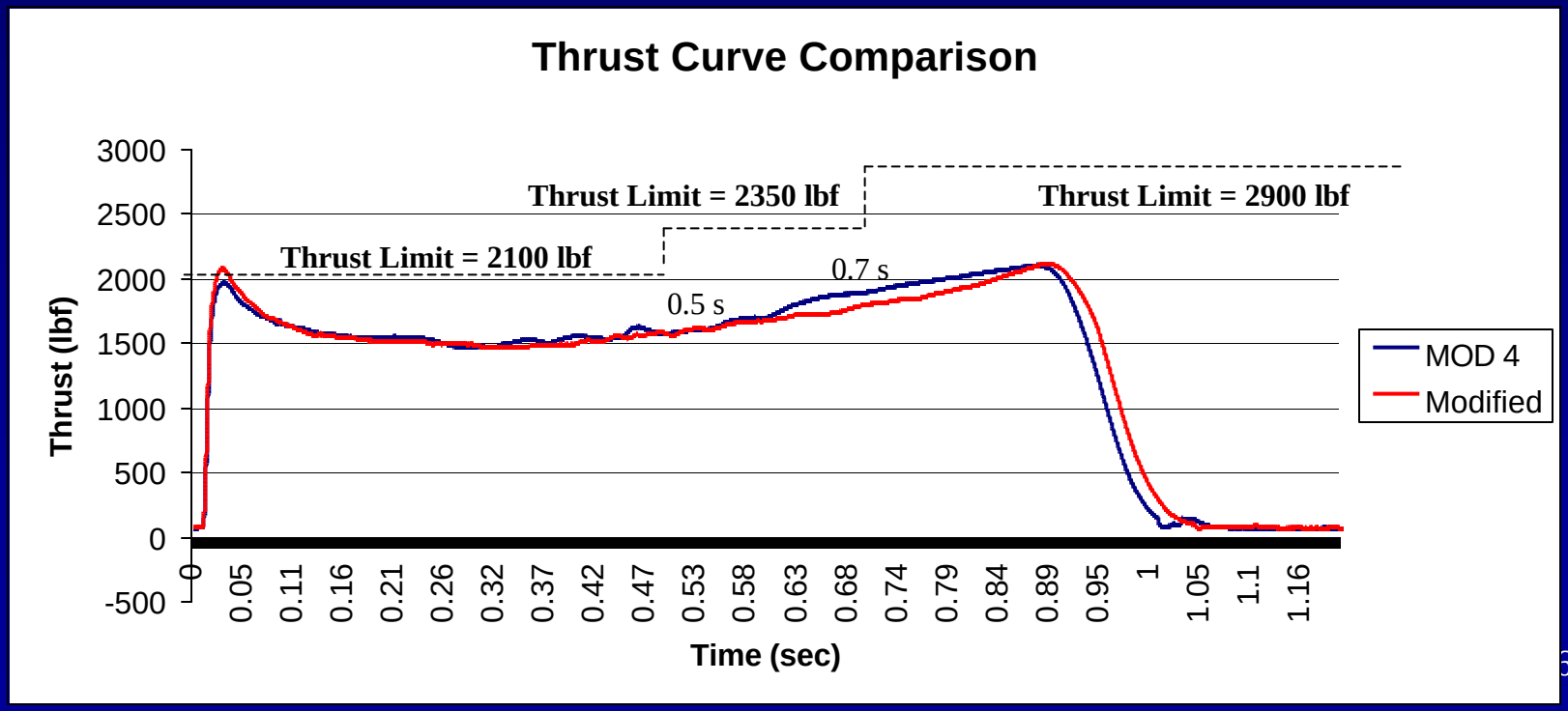
Internal Pressure Concerns

- **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**



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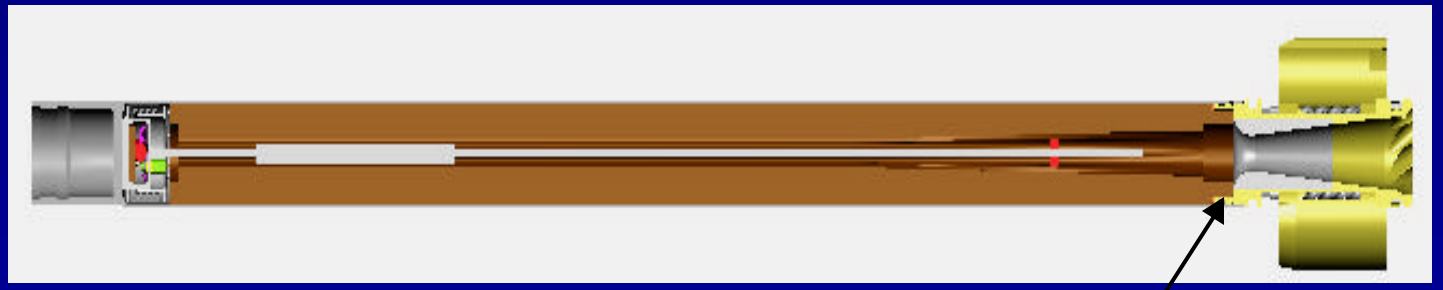
Pressure Differential Test

- 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



Lockwire joint

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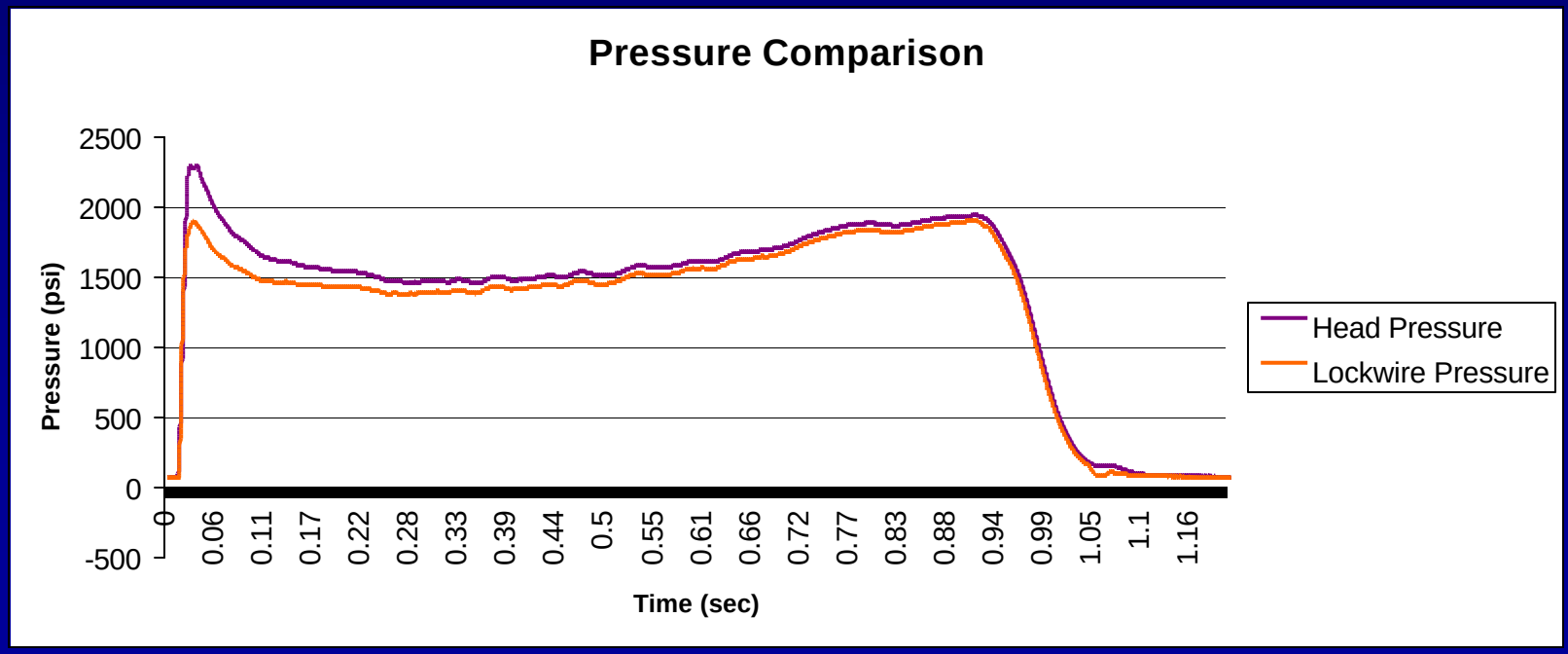
Pressure Differential Test

- **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**



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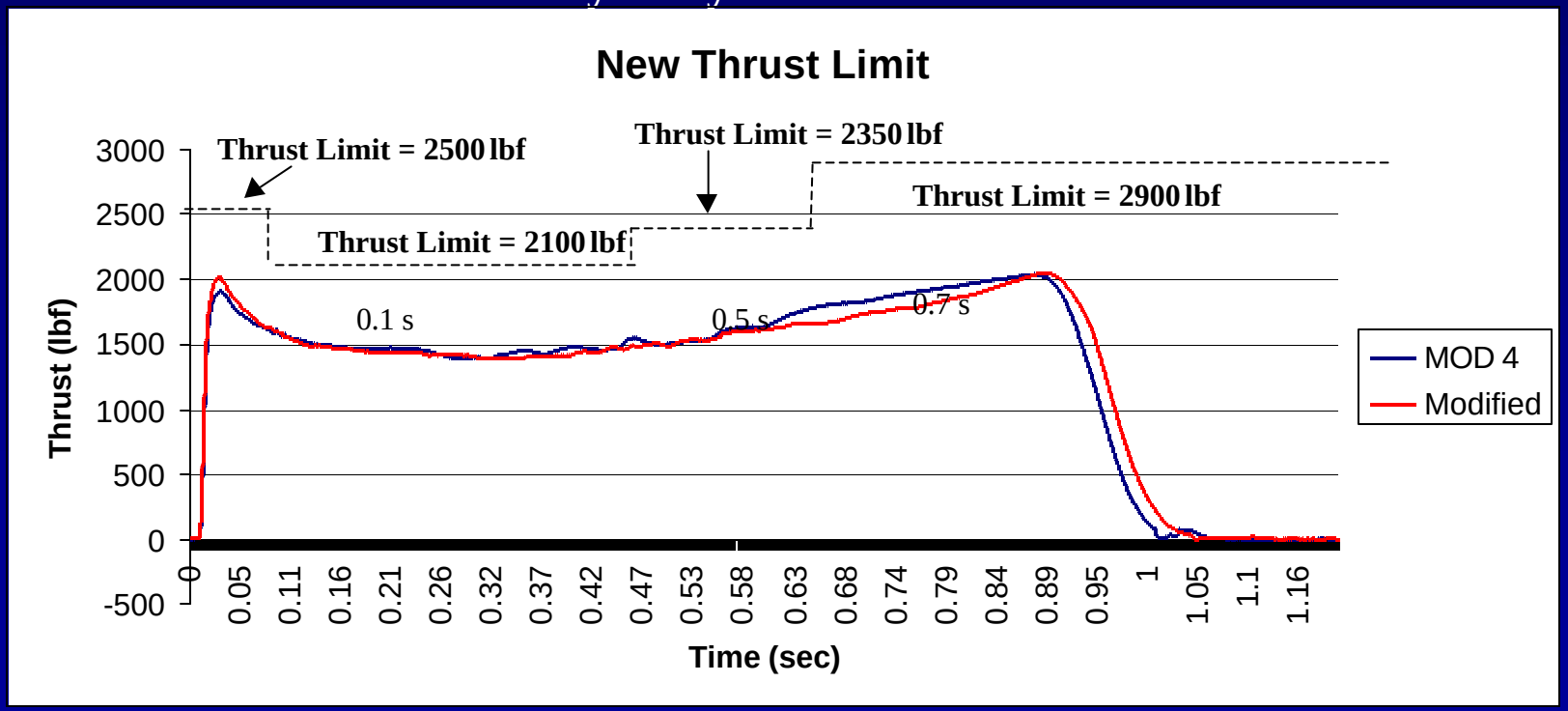
Pressure Differential Test Results

- **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**



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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

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Questions

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