DIRECT OBSERVATION OF MECHANICAL ABLATION

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Solid Rocket Motor Internal Insulation

Forward dome ("head end"), two basic designs:

**Boot/Flap**

**Slotted**
Internal Insulation Materials

Requirements include:

- High strain (rubbery)
- Good insulation
- Ablation and erosion resistant

Typically filled elastomers

- e.g.: silica-filled ethylene propylene diene monomer (EPDM)
- Substantial char swell during ablation
The "Flight-Amplified Erosion" Mystery

Recovered solid rocket motors show more forward dome internal insulation charring than static firings indicated

- 15 recovered flight motors
- Char depth "amplification" up to 2.3X
- Various rocket systems
- Various insulator materials
- Average accelerations up to 6 gs
Theories Put Forward

Flight-amplified erosion is caused by:

1. Buoyant flow effects increase convection and shear
2. Increased radiation due to acceleration forces on $\text{Al}_2\text{O}_3$ particles
3. Acceleration forces move more reactive gases adjacent to dome
4. Weak char layers pulled off by acceleration
Test Objectives and Approach

Objectives:

- Simulate pertinent flight conditions
- Observe insulation response

Approach:

- Use high-energy laser to simulate heat flux
  - Heat transfer is primarily radiation from propellant combustion products (~200 - 400 W/cm²)
  - Prior tests and analyses indicated shear unimportant at forward dome
- Use centrifuge to provide acceleration
- Use mirrors to keep the beam on the material specimen
Centrifuge Design – Side
Centrifuge Design – Top

Rotating Arm

- View Mirror
- Insulation Material Test Sample
- Sample Holder (Copper)
- Video Camera
- Amplifiers (Battery Powered)
- Direction of Rotation
- Rotating Arm
- Counterweight

Base

- Drive Motor (1 HP DC)
- Right Angle Drive
- Stabilizing Outrigger
- Leveling and Alignment Assembly (Typ of 3)

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Centrifuge as Fabricated
Rotating Arm Assembly

- Primary mirror
- Amplifiers
- Pyrometer
- Pyrometer mirror
- Secondary mirror
- Video mirror
- Test sample holder
- Slip rings
- Video camera
LHME Lewis Laser Evaluation Laboratory

At Wright Patterson AFB

LHME Laser:

15-kW CW CO₂ (10.6 micron)
Well-calibrated "flat-top" beam

"That's right, Bernie, this thing spins around and around."
Test Program Summary

Heat flux: 200, 300, 400 W/cm² (calibrated, uniform)

Acceleration: 0, 5, 10, 20 gs (0 - 250 RPM)

Insulation materials: 13 variations

Sample size: 1 inch Dia. baseline (also tested 2 inch Dia.)

Gas environment: N₂ baseline (also tested 90% N₂ + 10% O₂)

Data: Video, char depth & Avg. char rate, surface Temp., in-depth Temp. (some tests)

(see video examples)
Example Pyrometer Data: 053A Silica-EPDM

300 W/cm² & 0 gs
Example Pyrometer Data: 053A Silica-EPDM

300 W/cm² & 20 gs

Temperature (°R, thousands)

Time (seconds)
Average Char Rate: 053A Silica-EPDM

vs. acceleration at 300 W/cm²
Average Char Rate: 053A Silica-EPDM

vs. heat flux at 10 gs

Char Rate (mils/sec)

Heat Flux (W/cm²)
T/C instrumentation of elastomeric ablators with swelling and sometimes weak chars is problematic.
Example CMA Predictions

053A Silica-EPDM at 0 gs (no char removal)

(Char Rate (mils/sec) vs. Heat Flux (W/cm²))

(053A properties from Aerotherm HEEI program report)
Example HICAM Predictions

195 Silica-EPDM at 10 gs (with char removal)

HICAM = Hercules Inc. Charring and Ablation Model (Hercules now part of ATK)

Char permeability = $3 \times 10^{-11}$ ft$^4$/Lbf·sec
Char tensile strength = 515 psi
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LHMEEL staff (laser test facility)

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