DIRECT OBSERVATION OF MECHANICAL ABLATION

Charles Powars & Craig Derbridge

St. Croix Research
San Jose, CA
(408) 723-1216
capcap@aol.com
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 Al₂O₃ 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
- Optical Pyrometer
- 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)
Centrifuge as Fabricated
Rotating Arm Assembly

- Primary mirror
- Amplifiers
- Pyrometer
- Pyrometer mirror
- Secondary mirror
- Video mirror
- Test sample holder
- Slip rings
- Video camera
"That's right, Bernie, this thing spins around and around."
Test Program Summary

Heat flux: 200, 300, 400 W/cm^2 (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: N_2 baseline (also tested 90% N_2 + 10% O_2)

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
Average Char Rate: 053A Silica-EPDM

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

vs. heat flux at 10 gs
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)

(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
Acknowledgments

Air Force Ballistic Missile Organization (now part of AF Space & Missile Systems Center)

   Sponsor of this Small Business Innovation Research (SBIR) project

Hercules, Inc. (now part of ATK), particularly the late Blaine Christensen

   Project subcontractor provided advice and HICAM calculations

LHMEEL staff (laser test facility)

   Was part of AF Materials Laboratory, now part of AF Research Laboratory, Materials & Manufacturing Directorate