Fifth Annual Ablation Workshop

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DIRECT OBSERVATION OF MECHANICAL ABLATION

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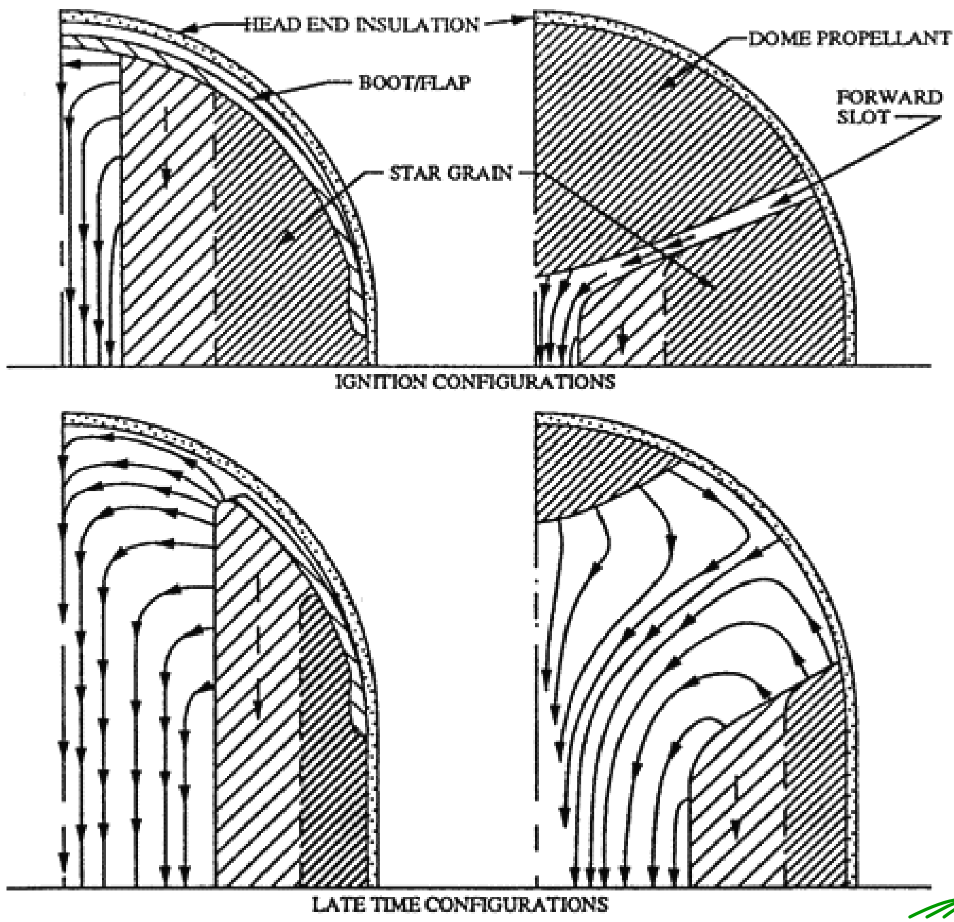
Solid Rocket Motor Internal Insulation

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

<u>**Boot/Flap**</u> <u>**Slotted**</u>



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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 Al_2O_3 particles**
3. **Acceleration forces move more reactive gases adjacent to dome**
4. **Weak char layers pulled off by acceleration**

Test Objectives and Approach

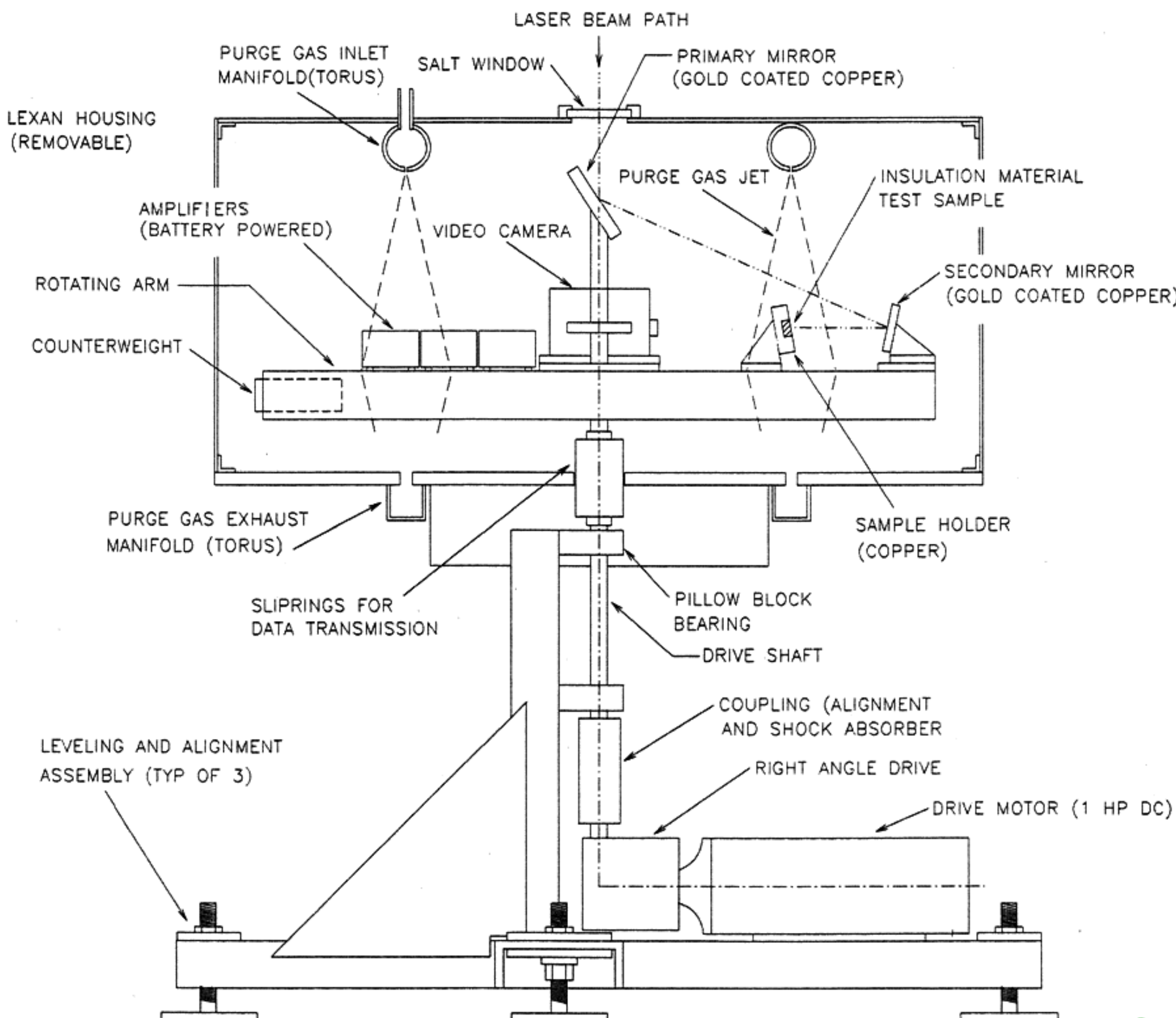
Objectives:

- **Simulate pertinent flight conditions**
- **Observe insulation response**

Approach:

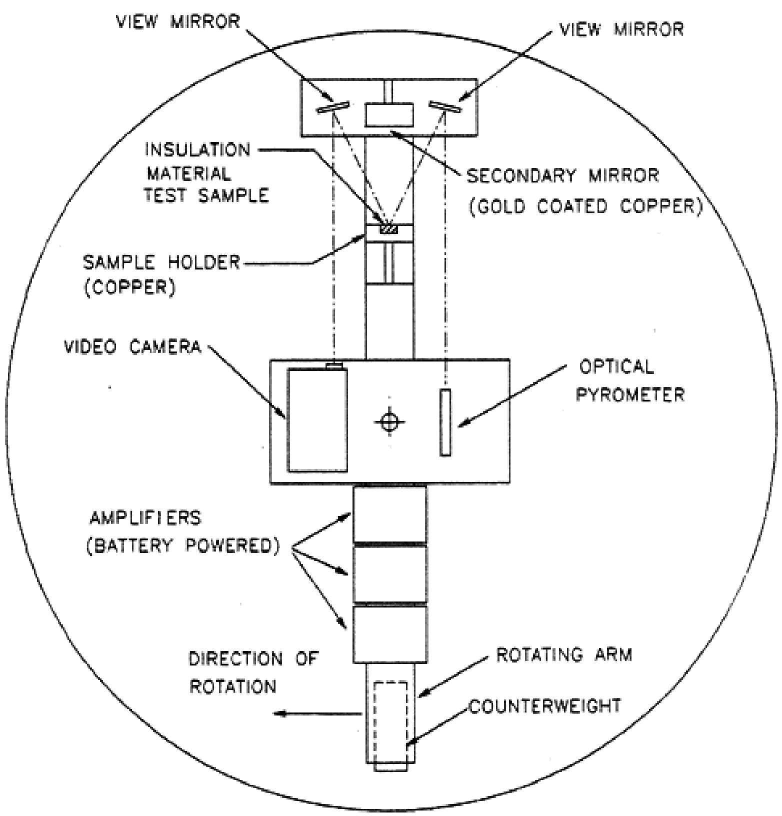
- **Use high-energy laser to simulate heat flux**
  - **Heat transfer is primarily radiation from propellant combustion products (~200 - 400 W/cm^2)**
  - **Prior tests and analyses indicated shear unimportant at forward dome**
- **Use centrifuge to provide acceleration**
- **Use mirrors to keep the beam on the material specimen**

Centrifuge Design – Side

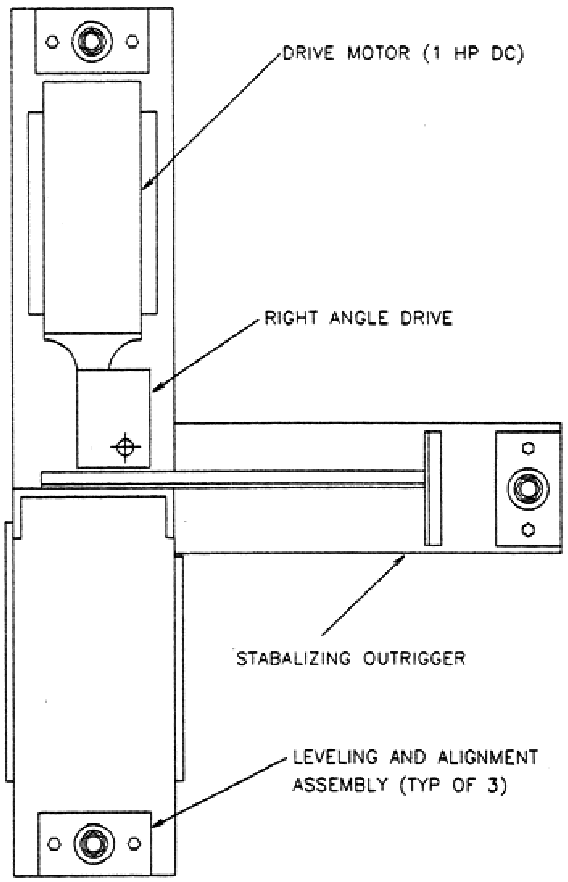


Centrifuge Design – Top

Rotating Arm



Base



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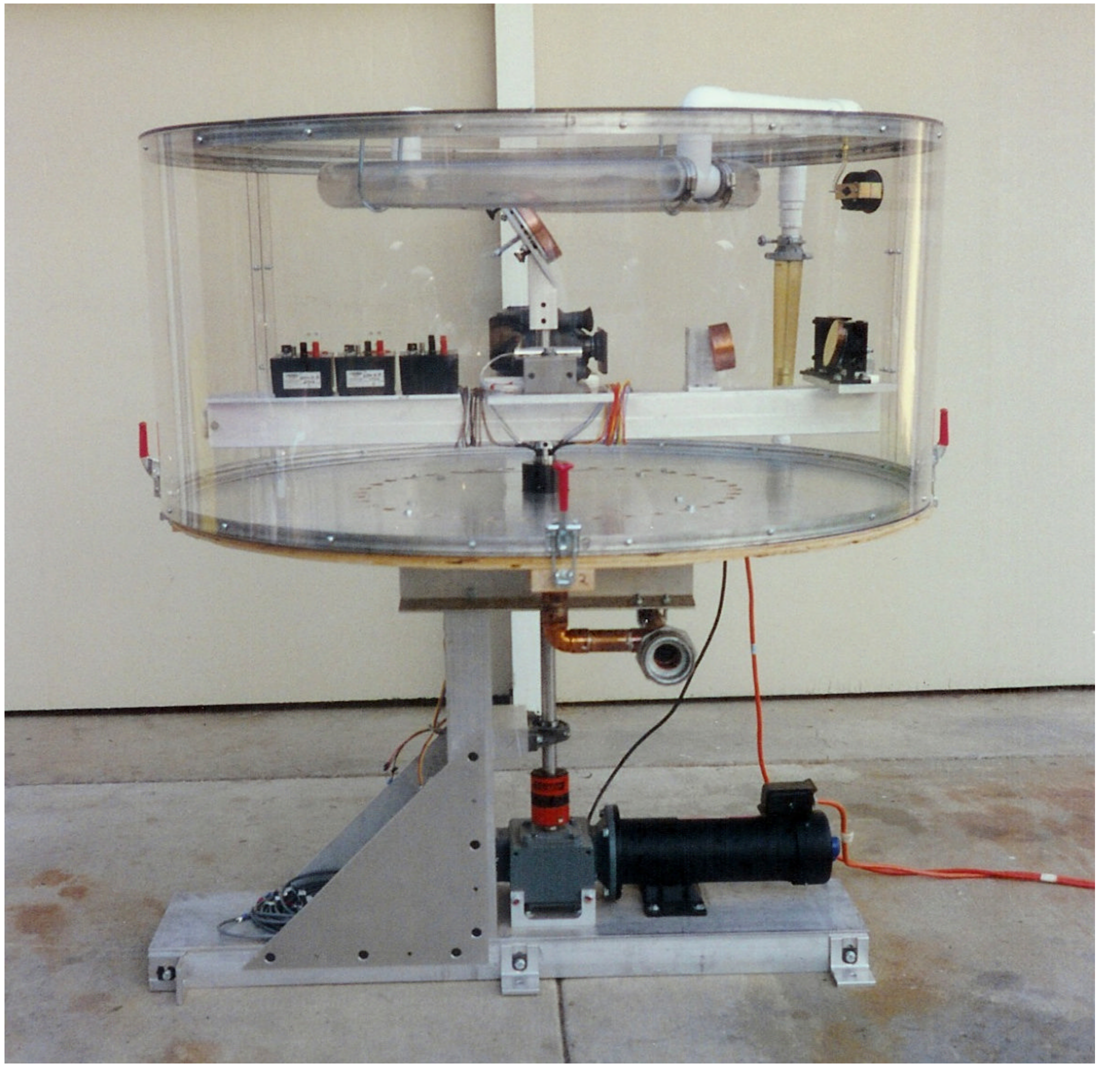
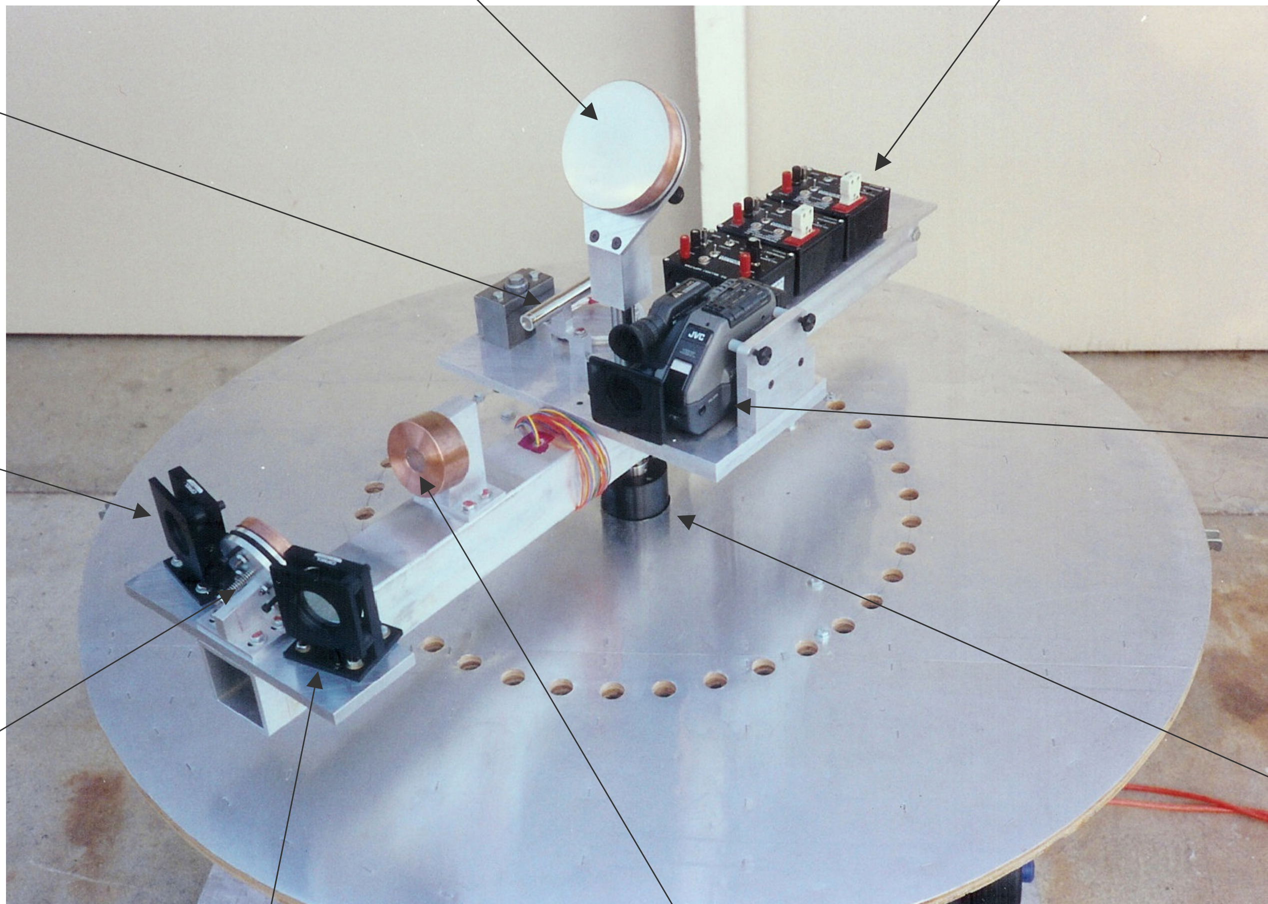
Centrifuge as Fabricated



Rotating Arm Assembly



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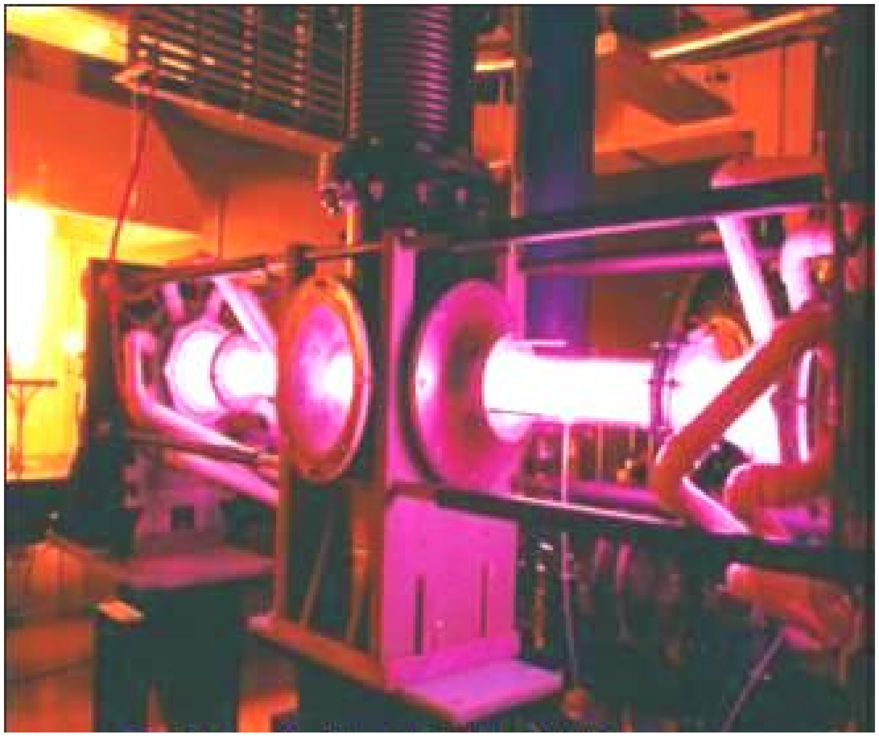
Laser Hardened Materials Evaluation Laboratory

At Wright Patterson AFB



LHMEL I Laser:

- **15-kW CW CO_2 (10.6 micron)**
- **Well-calibrated "flat-top" beam**

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

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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.)

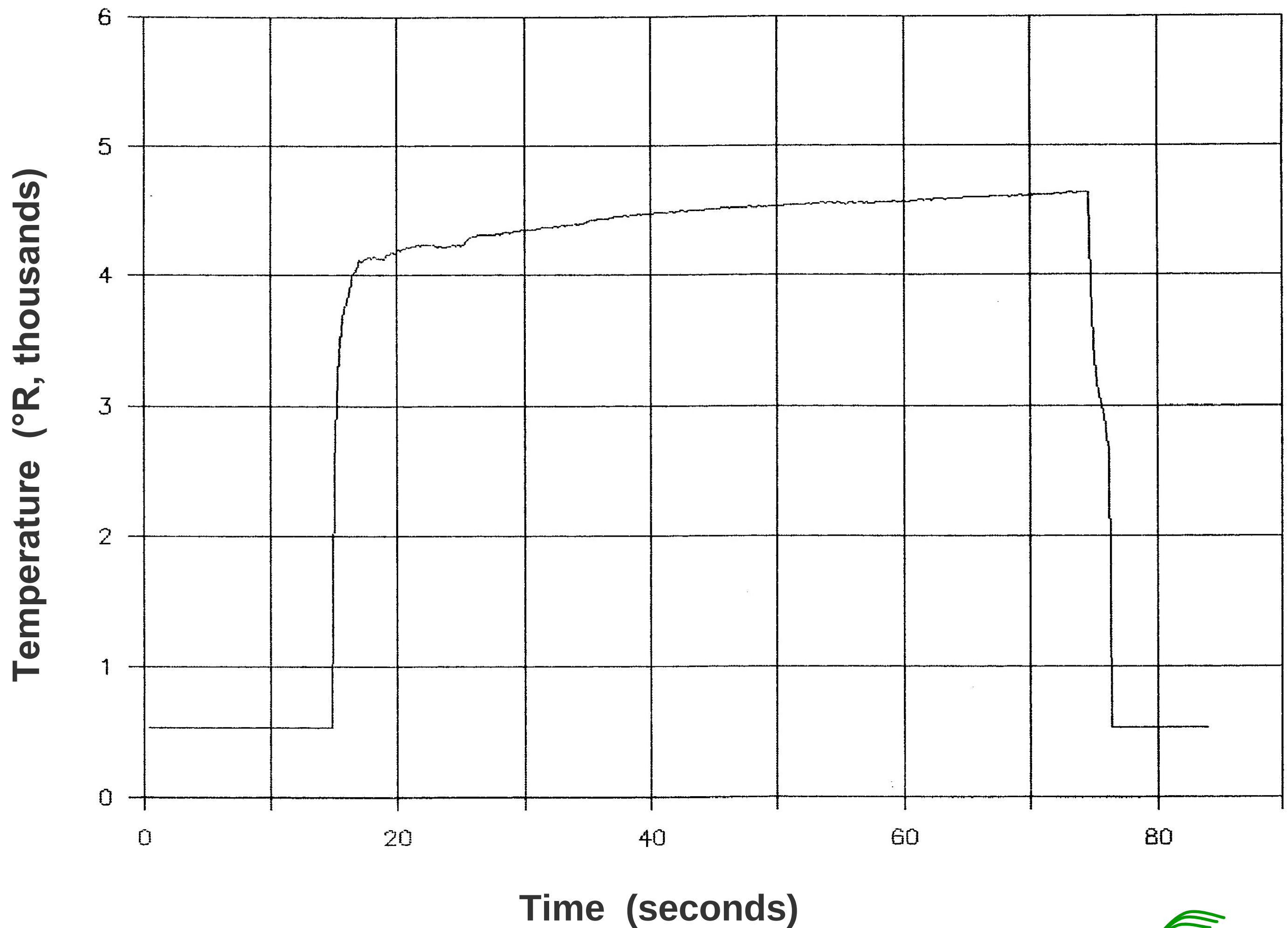
Gas environment: N_2 baseline (also tested 90% N_2 + 10% O_2)

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



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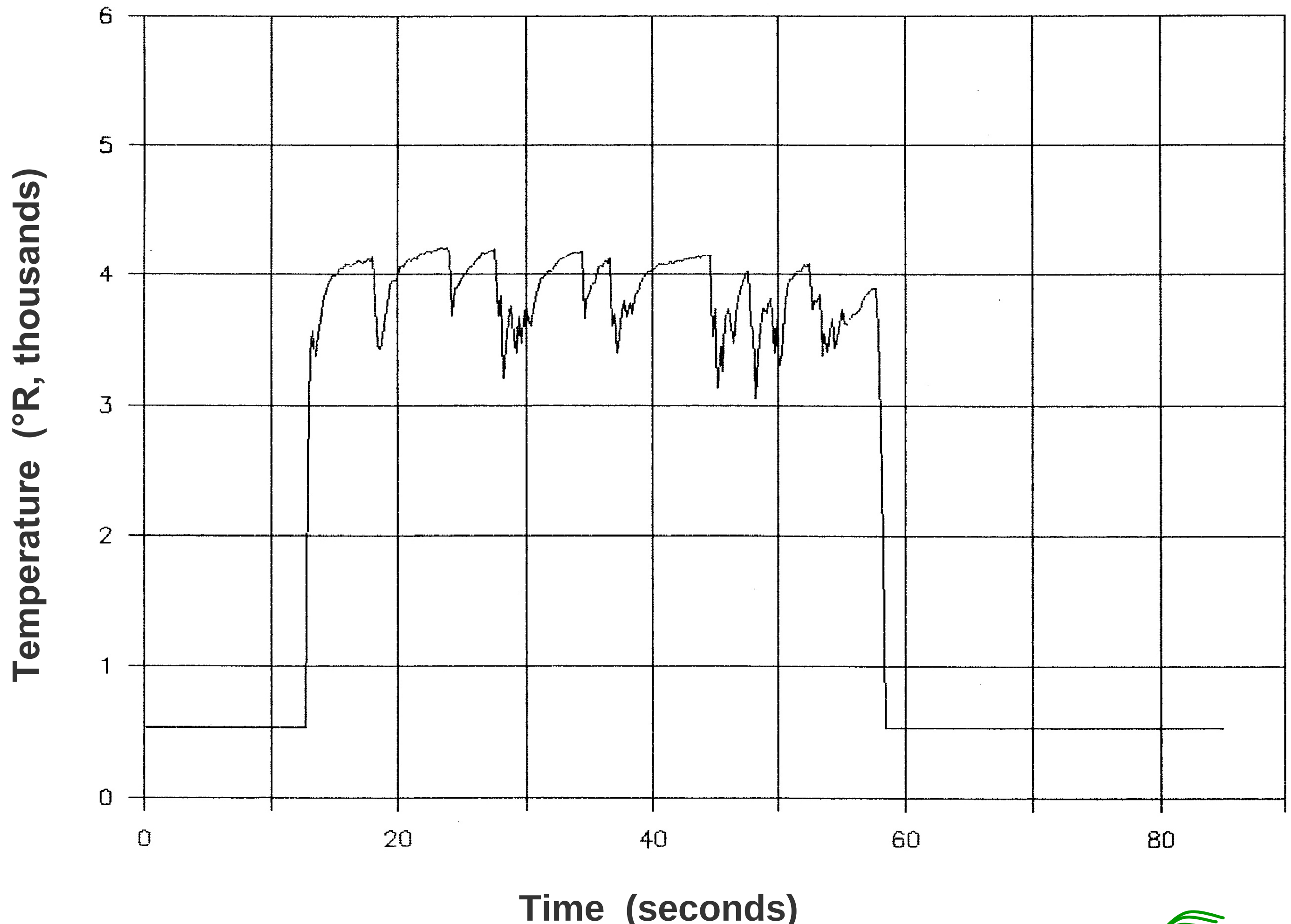
Example Pyrometer Data: 053A Silica-EPDM

300 W/cm² & 20 gs



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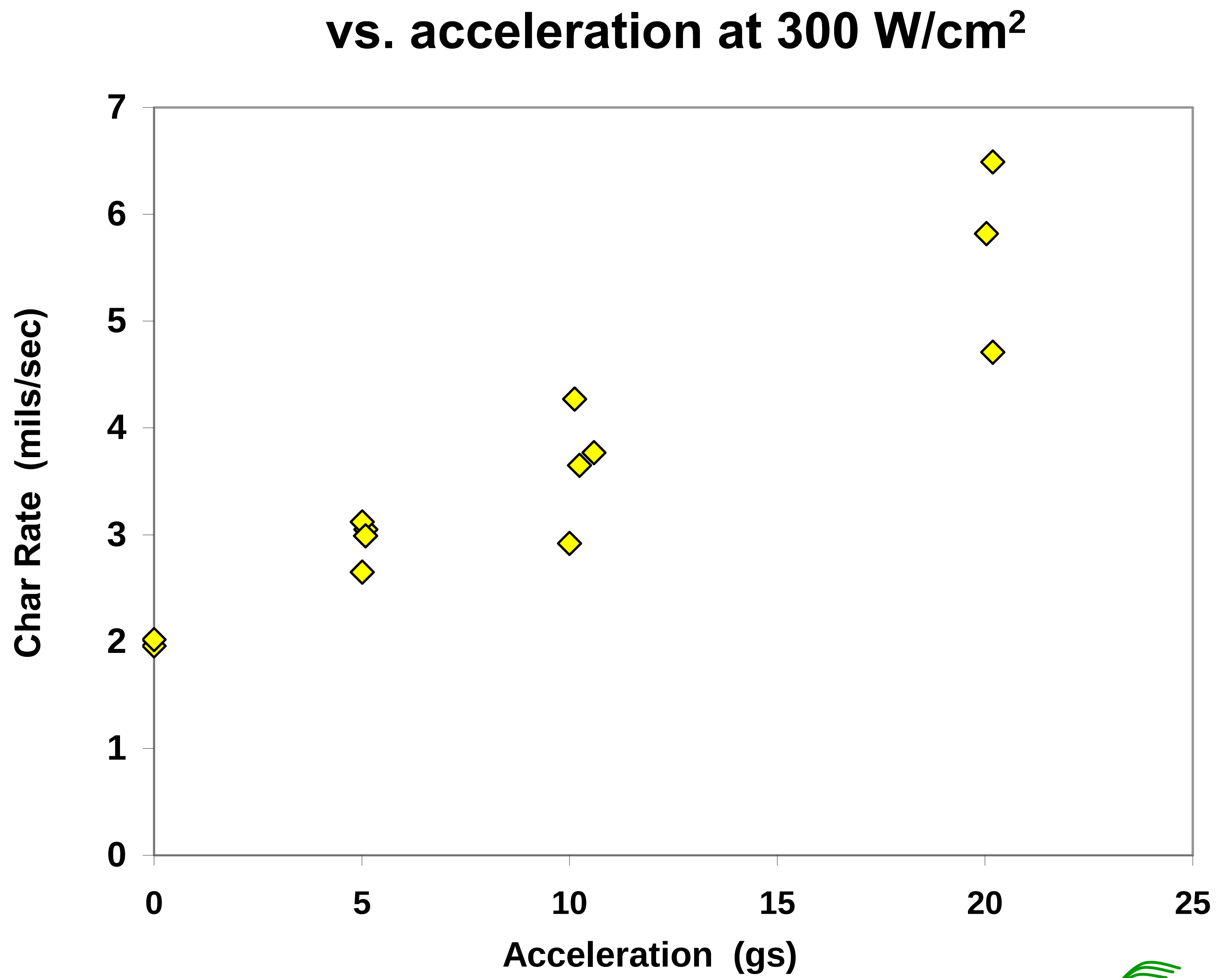
Average Char Rate: 053A Silica-EPDM



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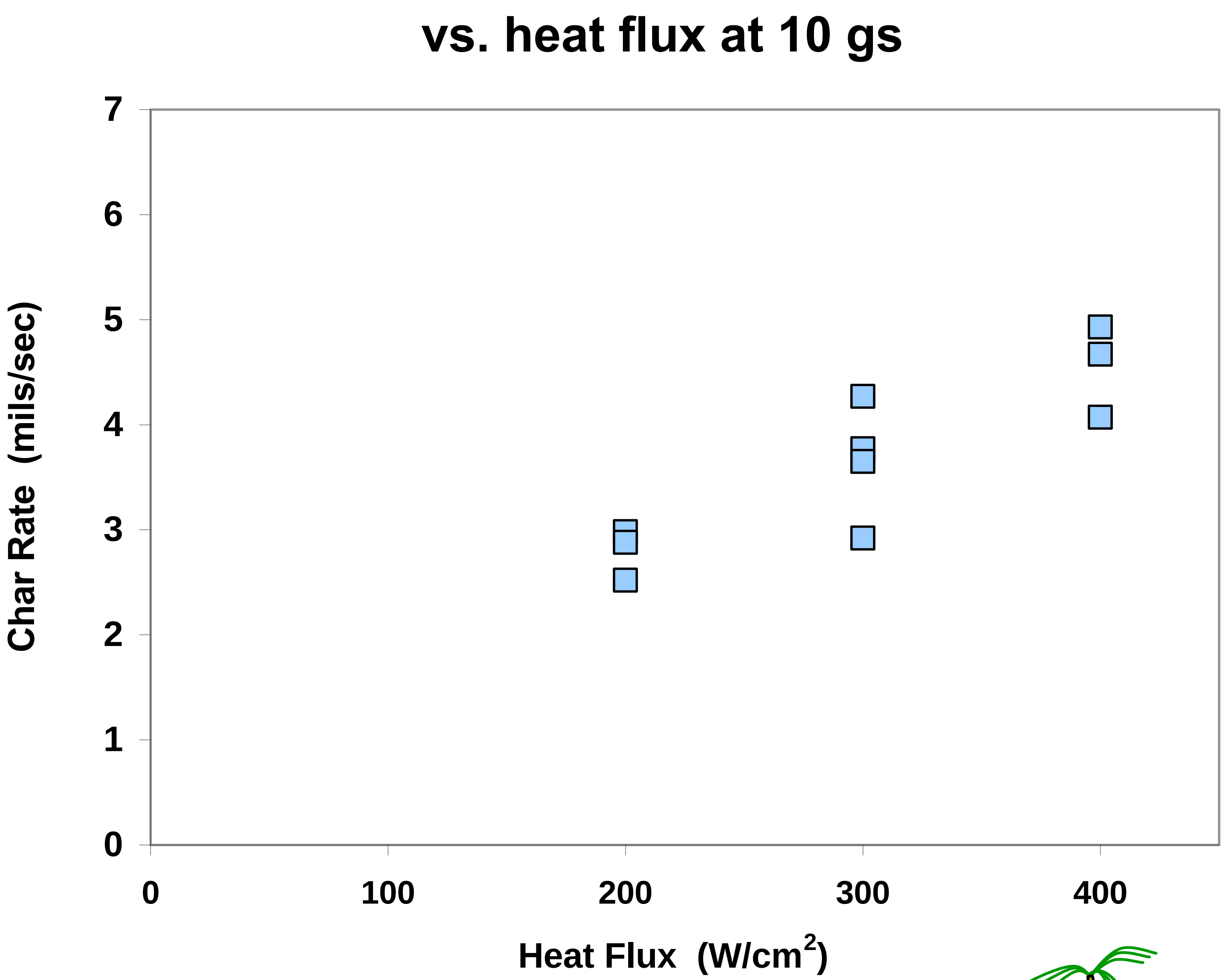
Average Char Rate: 053A Silica-EPDM



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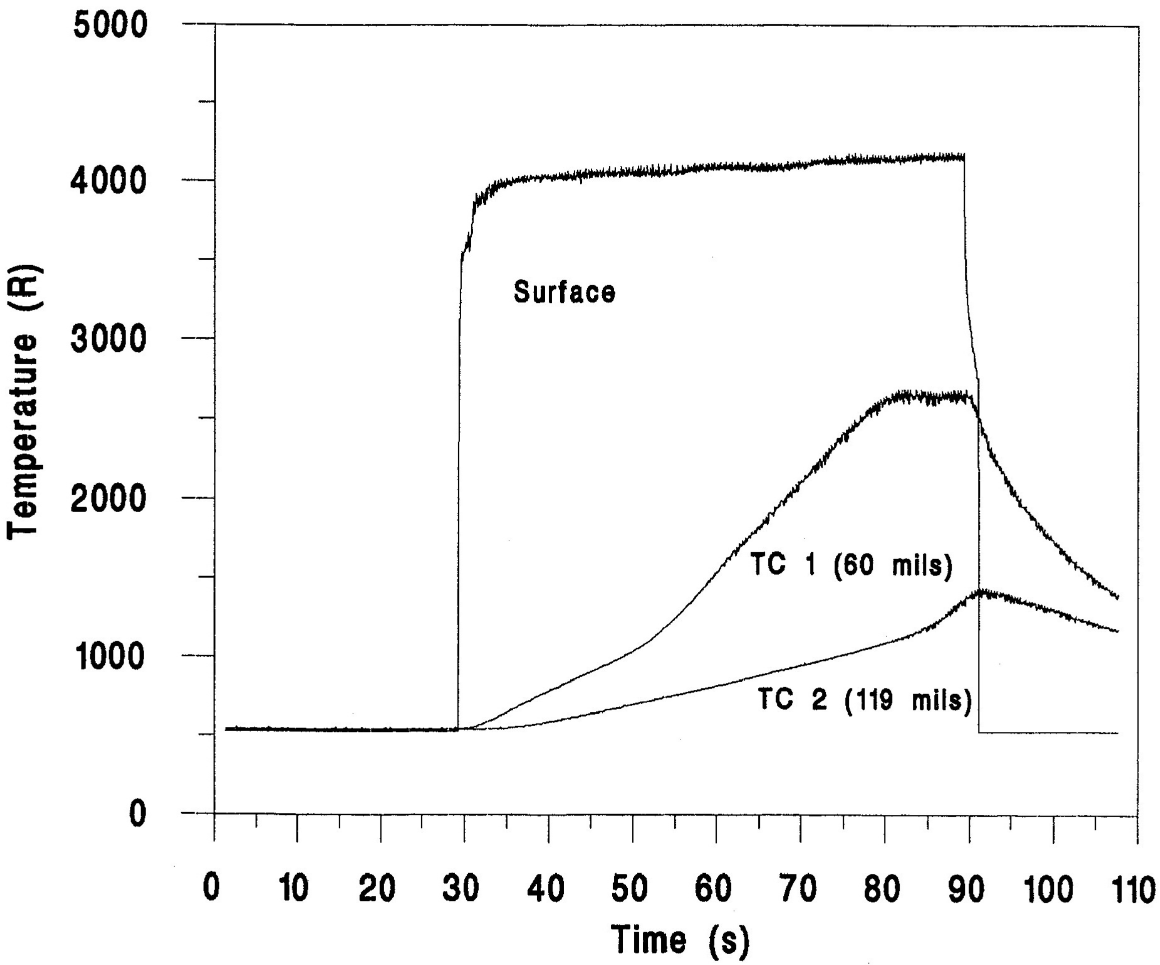
Example Thermocouple and Pyrometer Data

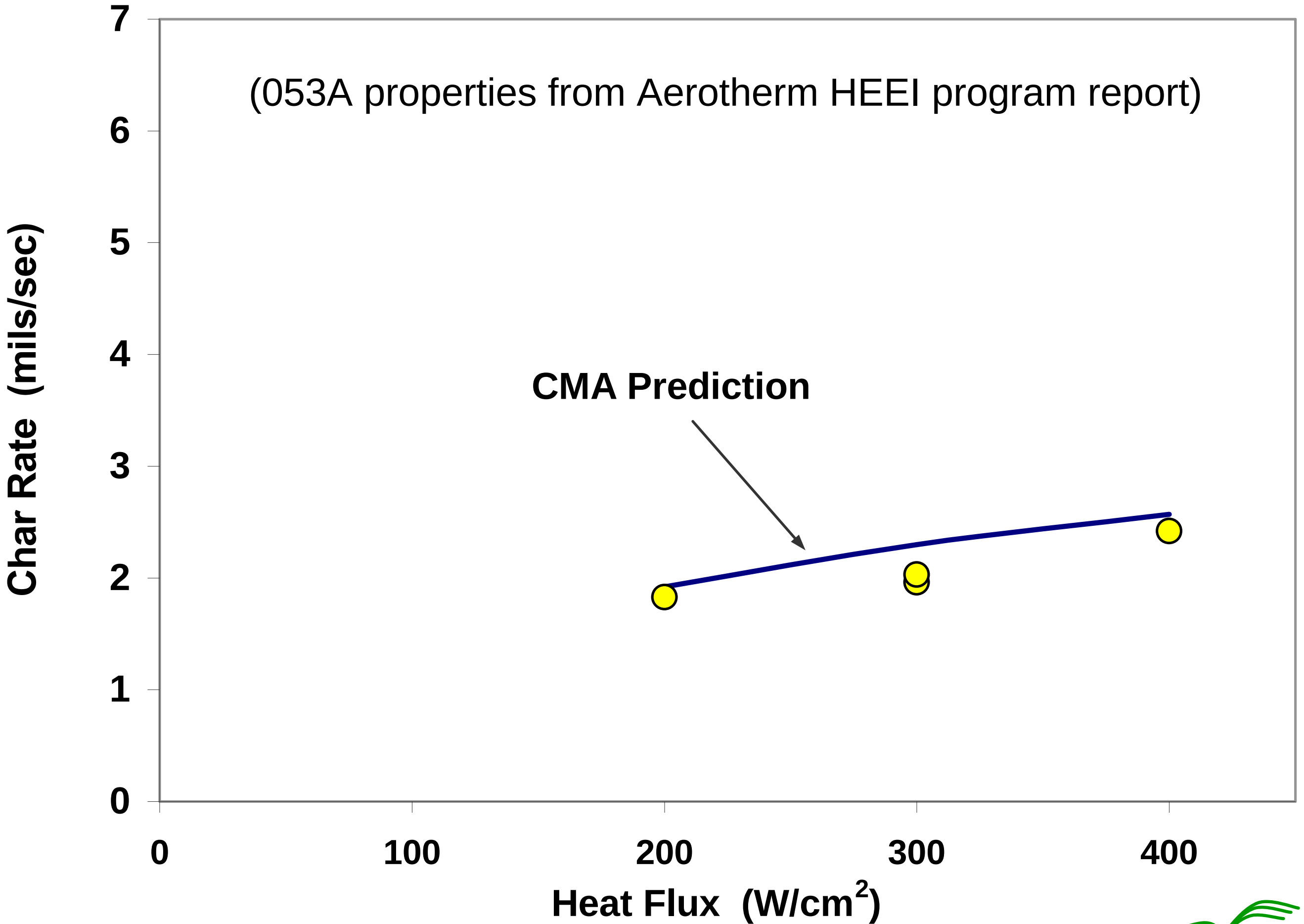
178 Kevlar-EPDM at 10 gs & 200 W/cm^2



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)



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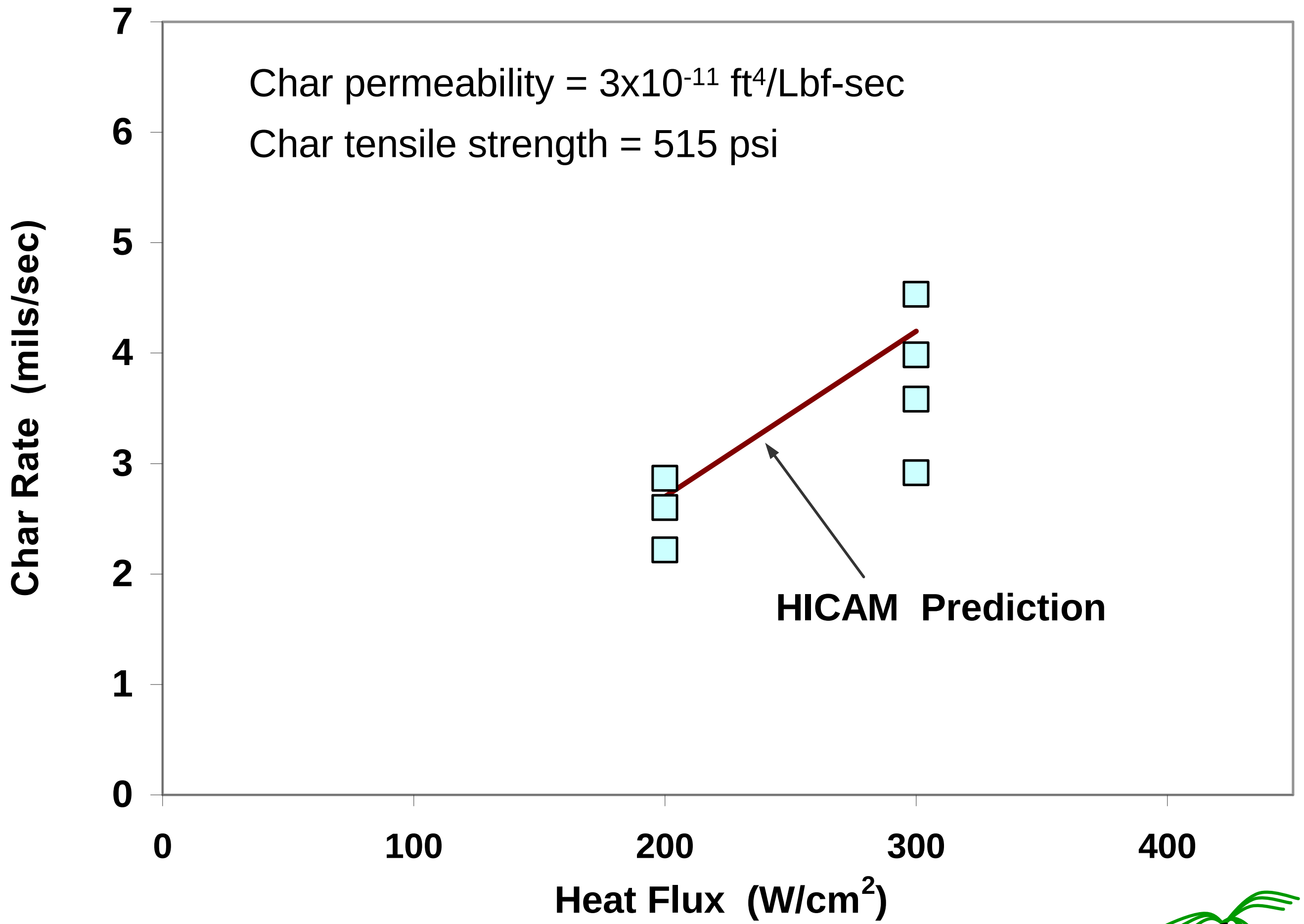
Example HICAM Predictions

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

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



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

LHMEL staff (laser test facility)

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